Hunt-for-Duration in the Corporate Bond Market*

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Abstract

This paper examines the duration hedging behavior in the corporate bond market by studying the investment decisions of life insurance companies, the largest institutional investor in this market. Using security-level data on insurers' bond holdings, I find that life insurers are tilting their corporate bond portfolios towards bonds with higher duration as the interest rates decrease to historical lows since the 2008 financial crisis. This hunt-for-duration behavior is due to life insurers' interest rate risk hedging to ensure better duration matching between their assets and liabilities. I further show that hunt-for-duration by life insurers can drive overpricing of corporate bonds when a negative monetary policy surprise hits.

JEL classification: G11, G12, G22, G23

Keywords: Institutional Investors, Corporate Bonds, Interest Rate Risk Hedging, Price Pressure

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1 Introduction

The U.S. corporate bond market is an institutional market, with institutional holdings accounting for around 75% of the amounts outstanding.[1] Given institutional investors' dominance, it is important to understand institution's investment behavior and how institutional trading affects prices in the corporate bond market.

Against the backdrop of the prolonged period of low interest rates since the 2008 financial crisis, I study the investment behavior of U.S. life insurance companies, the largest institutional holder of corporate bonds.[2] I find that as the interest rates drop to historical lows, life insurers tilt their corporate bond portfolios towards bonds with higher duration and such behavior can bear price implications.

Why would life insurers tilt their portfolios towards high duration when the interest rates decline? This can be explained by the liability-driven investment strategies of life insurance companies. To match the long-term payment commitments of their insurance products, life insurers invest largely in fixed income assets. As the interest rate falls, the values of liabilities and assets on the balance sheet of a life insurer both increase. The magnitude and speed of the increase depends on the duration and convexity of liabilities and assets. When a life insurer's balance sheet brings about negative convexity as the interest rate falls to a very low point, the duration of liabilities increases faster than assets, leading to a widening duration gap between liabilities and assets. To protect the balance sheet against further drop in the interest rate, life insurers need to increase the duration of their asset holdings. Borrowing the term from Domanski et al. (2017), throughout the paper, I call the duration hedging behaviour "hunt-for-duration".

To quantify the extent to which life insurers engage in hunt-for-duration, I employ two

[1] See https://www.federalreserve.gov/releases/z1/20200921/html/l213.htm.

[2] According to the U.S. Flow of Funds, in 2019 life insurance companies hold about 29% of the total amounts outstanding of corporate and foreign bonds. See https://www.federalreserve.gov/releases/z1/20200921/html/l213.htm.

approaches. The first approach adopts the characteristics-based demand model developed by Koijen and Yogo (2019) in the context of bonds. The model is micro-founded by investors with mean-variance preferences for returns, who consider that returns follow a factor structure and that both expected returns and factor loadings depend on assets' own characteristics. Under the above set-up, Koijen and Yogo (2019) prove that optimal portfolio weight depends on assets' observed characteristics and latent demand (unobserved characteristics to econometricians). Using security-level data on life insurers' bond portfolios, I estimate life insurers' characteristics-based demand model for corporate bonds, where portfolio weight is a logit function of bond characteristics including yield, duration, credit rating, liquidity, and latent demand. To address the issue of endogeneity of bond yield to latent demand in estimating the characteristics-based demand model, I use an instrumental variable that exploits the fact that institutional investors have an investment universe predetermined by their investment mandate.[3] When a bond issuer whose bond issues are included in the investment universe of more and larger investors, it then has a larger exogenous component of demand, which generates higher prices and hence lower yields that are orthogonal to latent demand.

I harvest the estimated coefficients on bond duration from the characteristics-based demand model and use them to capture life insurers' hunt-for-duration behavior. A larger coefficient on bond duration indicates that life insurers are tilting their portfolio more towards bonds with higher duration. I find that over time from year 2002 to 2017, life insurers have a heavier tilt towards high duration bonds when the 1-year Treasury yield (used as the interest rate indicator throughout the paper) is low and the slope of the yield curve (measured as the difference between 30-year and 1-year Treasury yields) is steep.

In the second approach, I compare the duration of life insurers' corporate bond portfolio

[3]Corroborating evidence for institutional investors' time-invariant investment universe of stocks is shown in Koijen and Yogo (2019). I show in Section 4 that institutional investors indeed invest in bonds issued by a relatively fixed subset of bonds issuers.

to that of the market portfolio. In particular, I construct the measure "excess duration" that captures the deviation of the duration of a life insurer's corporate bond portfolio from the bond-rating-matched benchmark, which is the average duration of all corporate bonds outstanding in the same rating group.[4] Constructing the measure in relative terms is important because the insurance companies are subject to risk-based capital charges based on the credit ratings of the bonds they invested in. As a consequence, life insurers have more discretion to engage in hunt-for-duration if they maintain the ratings of their holdings.

I document the negative correlation between the excess duration of life insurers' corporate bond portfolio and the interest rate with the specification that takes into account the dynamic changes in the excess duration following a shock to the interest rate. I also study the cross-sectional variation in hunt-for-duration, exploiting the differences in regulatory capital constraints faced by life insurers, as life insurers with higher asset-liability mismatch are charged a higher capital reserve. The results show that more regulatory-constrained insurers tend to hunt for duration more.

Evidence for hunt-for-duration is found not only from snapshots of life insurers' bond holdings, but also from their bond transaction activities. In a similar empirical setup as Becker and Ivashina (2015), I investigate life insurers' acquisitions of newly-issued bonds from the primary market and their trading in the secondary market. I separate the sample period into two sub-periods: a period with the 1-year Treasury yield higher than 1% (before year 2009) and a period with the yield at most 1% (after year 2009). The results show that life insurers buy (sell) more bonds that have higher (lower) excess duration. Furthermore, the correlation between life insurers' trade of a bond and its excess duration is even stronger over the sub-period of low interest rates.

The importance of life insurance companies' portfolio duration management lies in that

[4] Ozdagli and Zhang (2019) and Choi and Kronlund (2018) have constructed the measures of reaching-for-yield in a similar spirit.

it can explain other patterns found in the literature. For instance, without controlling for bond excess duration, during times of low interest rates, life insurers' propensity to invest in bonds is an increasing function of bond yield (which is reaching-for-yield in Becker and Ivashina (2015)). However, with inclusion of bond excess duration, the association between life insurers' trade of a bond and its yield weakens significantly, indicating that life insurers' inclination for buying bonds with higher yield in times of low interest rates is mainly prompted by increasing the duration of their bond portfolios for hunt-for-duration purposes.

To illustrate that hunt-for-duration is unique to life insurance companies due to their liability-driven portfolio management, I use other major bond investors as a comparison group. Specifically, I trace the evolution of portfolio duration of the mutual funds, who are the second largest participants in the corporate bond market. Different from life insurers, the investment strategies of mutual funds are asset-driven. Mutual fund managers are subject to short-term performance monitoring and hence are averse to holding long-term bonds that are volatile as the interest rates fluctuate. I find that mutual funds, in contrast with life insurers, are shifting their corporate bond portfolios toward lower duration as the interest rates decrease. Therefore, the comparison confirms that hunt-for-duration is not a general feature in the corporate bond market, but a specific one accounted for by the specific institutional setting of life insurance companies.

Having documented the hunt-for-duration behaviour of life insurance companies, I investigate whether this behavior bears price impact on corporate bonds. To address this question, I examine the returns of bond purchases associated with hunt-for-duration. I consider bonds in the top two quintiles of excess duration bought by life insurers following a quarter with a negative monetary policy shock as bonds involved in hunt-for-duration-motivated trades. I find that during quarters following a negative monetary policy shock, in the top two quintiles of excess duration, bonds that are purchased most heavily by life insurers have abnormal returns significantly higher than bonds that are only lightly bought by life insurers, and the upward pattern in abnormal returns gradually reverses. Such price pattern is absent in other quarters. I also conduct the same examination on bonds in the bottom two quintiles of excess duration. There is no evidence of upward price pressure from life insurers buying over all quarters. Furthermore, I calculate the portfolio returns of an investment strategy that involves longing bonds acquired by life insurers for the purpose of hunt-for-duration. The strategy earns a significant negative alpha. Overall, the results provide evidence corroborating that life insurers' hunt-for-duration behaviour can engender price impacts.

This paper is related to the literature that studies the investment behaviour of insurance companies. Ozdagli and Zhang (2019) proposes and validates a model of duration matching with adjustment costs to explain why life insurance companies don't fully close the duration gap between asset and liability as the interest rates decline. Domanski et al. (2017) study the hunt-for-duration behaviour in the context of European life insurance companies and government bonds. Becker and Ivashina (2015) finds signs of reaching-for-yield (i.e., life insurers tilt towards riskiest bonds within a bond rating group) over the pre-crisis period from 2004Q3 to 2007Q2. Ellul et al. (2011) find that in the event of corporate bond downgrades, regulatory-constrained insurance companies are forced to sell downgraded bonds, thereby creating a downward price pressure. Ellul et al. (2015) show that historical accounting rules, interacted with capital regulation can induce life insurers to resort to gains trading.

The rest of the paper proceeds as follows. In Section 2, I discuss the institutional settings of life insurance companies and how the institutional features could lead life insurers to engage in hunt-for-duration as the interest rates decline. Section 3 discusses the data. In section 4, I estimate life insurers' demand for bond duration using the characteristics-based demand model. In section 5 and 6, I construct the measure of excess duration of life insurers' portfolio and present the empirical results. In Section 7, I investigate the effects of hunt-for-duration on bond prices. Section 8 concludes.

2 Why hunt-for-duration in a low interest rate environment?

2.1 The institutional setting: life insurance companies

There are several unique institutional features that are crucial to life insurance companies' bond investment decisions. These features include life insurers' asset and liability characteristics, regulatory capital requirements, and accounting rules. These factors collectively explain why life insurers have an appetite for bonds with long duration in times of low interest rates.

The U.S. insurance industry is regulated under the National Association of Insurance Commissioners (NAIC) risk-based capital (RBC) system.[5] Under the RBC system, insurance companies are subject to a minimum capital requirement based on the amount of risk to which they are exposed. To determine the minimum level of capital an insurance company must maintain, the RBC formula considers four risks factors: asset risk, underwriting risk, interest rate risk, and all other business risk. One risk factor widely discussed in the literature (e.g., Becker and Ivashina (2015) and Ellul et. al (2011)) has to do with the asset risk. As bonds are a major investment vehicle for insurers, insurance companies are restricted from loading on excessive asset risk through holding bonds with low credit ratings. The restrictions are imposed by charging exponentially increasing capital requirements on bonds that belong to different NAIC risk categories. For each $100 invested, the capital charge for bonds in NAIC category 1 (bonds rated AAA/AA/A) is $0.30, whereas the capital charge for bonds in NAIC category 6 (bonds rated CC or below) is $19.50.[6]

[5] For a brief background on the RBC system: https://content.naic.org/cipr_topics/topic_risk_based_capital.htm

[6] See https://www.naic.org/documents/committees_e_capad_investment_rbc_wg_related_irbc_factors.pdf

The risk factor related with this paper is the interest rate risk. Given that life insurance is a liability-driven business supported by investments in fixed-income assets, life insurers are vulnerable to interest rate movements. To contain life insurers' exposure to interest risk, NAIC imposes capital charges on mismatch in asset and liability cash flows. Asset and liability can be gravely mismatched as interest rates drop to historical lows. As an interest risk strategy to ensure better matching between assets and liabilities, life insurance companies increase the duration of their assets (i.e., hunt for duration) during times of persistently low interest rates.[7] Details on a liability-driven investment strategy that attempts to hedge against interest rate risk is presented in Section 2.2.

One concern could be that bonds with longer duration are subject to greater market value movements as the interest rate changes. However, according to NAIC guidelines, insurance companies report their bond holdings using historical cost accounting (HCA). That is, bonds are valued at amortized cost rather than market value (Ellul, Jotikasthira, Lundblad, and Wang 2017). Therefore, even though prices of longer-duration bonds are more volatile in a changing interest rate environment, unless the bonds are sold, HCA shields insurance companies from market value fluctuations of their bond holdings.

2.2 Stylized example of duration-matching

The balance sheet identity states that a company's equity value is determined by the difference in the value of its asset and liability. A change in the interest rate can affect the values of asset and liability, and hence the equity value. The sensitivity of value to interest rate is measured by duration. When the duration of a company's asset differs significantly from that of its liability, the company has a duration mismatch, which puts the company at risk to interest rate changes. To protect its equity from fluctuations in interest rate, a

for the complete capital charge scheme for the six NAIC risk categories of bonds.

[7]For brief overview of impact of low interest rates on life insurers: https://content.naic.org/cipr_topics/topic_low_interest_rates.htm

company engages in duration-matching to ensure that the duration of its asset aligns well with that of its liability. Domanski, Shin, and Sushko (2017) provide a stylized description of duration-matching in the context of life insurance companies. For illustrative purpose, I summarize the explanation in this section.

Life insurance companies sell long-term products, such as annuities, with guaranteed level of income over the life of policy. To fulfill the long-term payment commitments to their policyholders, life insurance companies invest largely in bonds with long maturities. To capture the above characteristics of a life insurer's balance sheet, think of the liability of a life insurer as a growing perpetuity with a first payment of C and growth rate g. On the asset side, the life insurer holds y units of T-year risk-free zero-coupon bond with principal amount 1 and yield r.

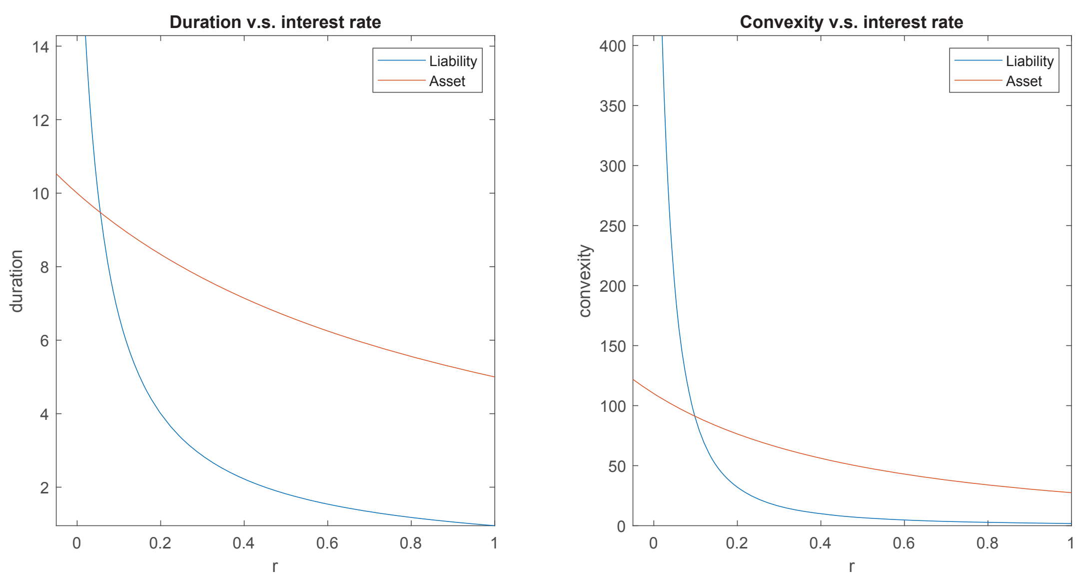
The first row of Table I gives the value of the life insurer's liability and asset using yield r as the discount rate. When the interest rate r decreases, the values of liability and asset both increase, but with different sensitivities. The sensitivities to interest rate of asset and liability, as measured by modified duration, are presented in the second row of Table I. The left panel of Figure I plots the duration of liability and asset against the interest rate. Notice that as the interest rate r approaches zero, the duration of liability is larger than that of asset. Furthermore, the duration mismatch between liability and asset widens at an increasing rate. As shown in the last row of Table I and Panel B of Figure I, this is due to the fact that the convexity of liability, which measures how the duration of liability responds to interest rate changes, exceeds that of asset. To summarize, since the liability value increases faster the asset value during times of low interest rates, to protect its balance sheet against interest rate risk, the life insurer needs to increase the duration of its asset. As in Domanski, Shin, and Sushko (2017), I call this duration hedging behaviour "hunt-for-duration" throughout the paper.

Table I: Value, duration, and convexity of asset and liability

	Asset	Liability
Value (V)	$\frac{1}{(1+r)^T}$	$\frac{C}{r-g}$
Modified duration ($-\frac{1}{V}\frac{dV}{dr}$)	$\frac{T}{1+r}$	$\frac{1}{r-g}$
Convexity ($\frac{1}{V}\frac{d^2V}{dr^2}$)	$\frac{T(T+1)}{(1+r)^2}$	$\frac{2}{(r-g)^2}$

Notes: This table lists the value, modified duration, and convexity of a life insurance company's asset and liability. As in Domanski, Shin, and Sushko (2017), the assumption is that asset consists of T-year risk-free zero coupon bonds, and that liability is a growing perpetuity with coupon C and growth rate g. The discount rate r is the yield of the T-year risk-free zero coupon bond.

Figure I: Duration and convexity against interest rate



Notes: This figure plots the modified duration (left graph) and convexity (right graph) listed in Table I as a function of interest rate r. The parameters used are $T = 10$ and $g = -0.05$, where g is calibrated by Domanski, Shin, and Sushko (2017) using $D_{L,t} = 1/(r_t^{T=25} - g)$, where $D_{L,t}$ and $r_t^{T=25}$ are the duration of liability and 25-year zero-coupon euro swap rate in year t, respectively. To obtain g, year 2013 numbers are used: $r_{t=2013}^{T=25} = -0.12\%$, and $D_{L,t=2013} = 20.5$, according to EIOPA (2014).

3 Data

Data used in this empirical study come from multiple sources: National Association of Insurance Commission (NAIC) Schedule D filings, Morningstar, enhanced Trade Reporting and Compliance Engine (TRACE), and Mergent Fixed Income Securities Database (FISD). The data period spans from 2002 to 2017.

NAIC Schedule D filings consist of transaction and year-end position data of life insurance companies and P&C insurance companies. Part 1 of NAIC Schedule D provides insurers' year-end bond holding information including bond identification, holding size, and other accounting items. Part 3 to 5 include insurers' transaction records with transaction date, bond identification, trade size, price, direction, and counter-parties. One important thing to notice is that the transaction data records all trades that result in change of bond holding positions, including market buy and sell transactions as well as non-market transactions such as calls and maturities.[8]

Holding positions at the end of a given quarter in year t can be backed out through combining the reported year-end positions of year $t-1$ with transactions up until the end of the given quarter. I need both market and non-market transactions to infer quarter-end positions. However, when studying the trading activities of insurance companies, I use only market transactions.

Quarterly snapshots of bond holdings of mutual funds are obtained from Morningstar. I choose funds whose prospectus objective stated in Morningstar is corporate bond, since my focus is on funds that invest in corporate bonds.

I collect data on bond characteristics from Mergent FISD. This dataset contains bond-specific information such as coupon rate and payment frequency, maturity date, issue amount

[8] Transaction type can be identified in the counter-party field. Non-market transactions are those with counter-party field listed as call, cancel, conversion, direct, exchange, maturity, pay-down, put, redemption, sinking fund, tender, transfer, etc.

outstanding, option features, bond type, and industry. In addition, Mergent FISD records historical bond-level credit ratings issued by S&P, Moody's, or Fitch. I determine a bond's rating by the following rule.[9] When all three rating agencies rate a bond, I use the middle rating. If two agencies rate a bond, I use the lower rating. If only one agency rates a bond, that single rate is used. Each letter rating is assigned to a number. Specifically, AAA corresponds to 1, $AA+$ corresponds to 2, ..., C corresponds to 21, and D corresponds to 22. Bonds with numerical ratings from 1 to 10 are investment-grade ($AAA+$ to $BBB-$). Non-investment-grade bonds ($BB+$ or lower) have numerical ratings above 10.

Price data of corporate bonds are from enhanced TRACE. TRACE dataset reports transaction-level information including date, size, and price of corporate bond trades. I follow Dick-Nielson (2009) and Bessembinder et al. (2009) to clean up the price data. I delete trades that are cancelled, adjust trades that are corrected or reversed, and remove double-counting of agency trade. Quarter/month-end price of a bond is obtained by weighting prices by size of all trades taking place on the last day during which the bond was traded in the quarter/month. Bond yield in quarter/month t is calculated using its quarter/month-end price and detailed cash flow information from Mergent FISD. Modified duration, which reflects price sensitivity to change in yield, is then computed based on bond price, yield, and cash flow data. Quarterly/monthly returns of a bond in quarter/month t is calculated as relative change in price from quarter/month $t-1$ to t, factoring in accrued interest and coupon payment.[10]

I restrict my sample to fixed-rate U.S. dollar corporate debentures and medium-term notes in the industrial, financial, and utility sectors. I exclude convertible bonds since this

[9] See p.25 of https://www.bbhub.io/indices/sites/2/2017/03/Index-Methodology-2017-03-17-FINAL-FINAL.pdf

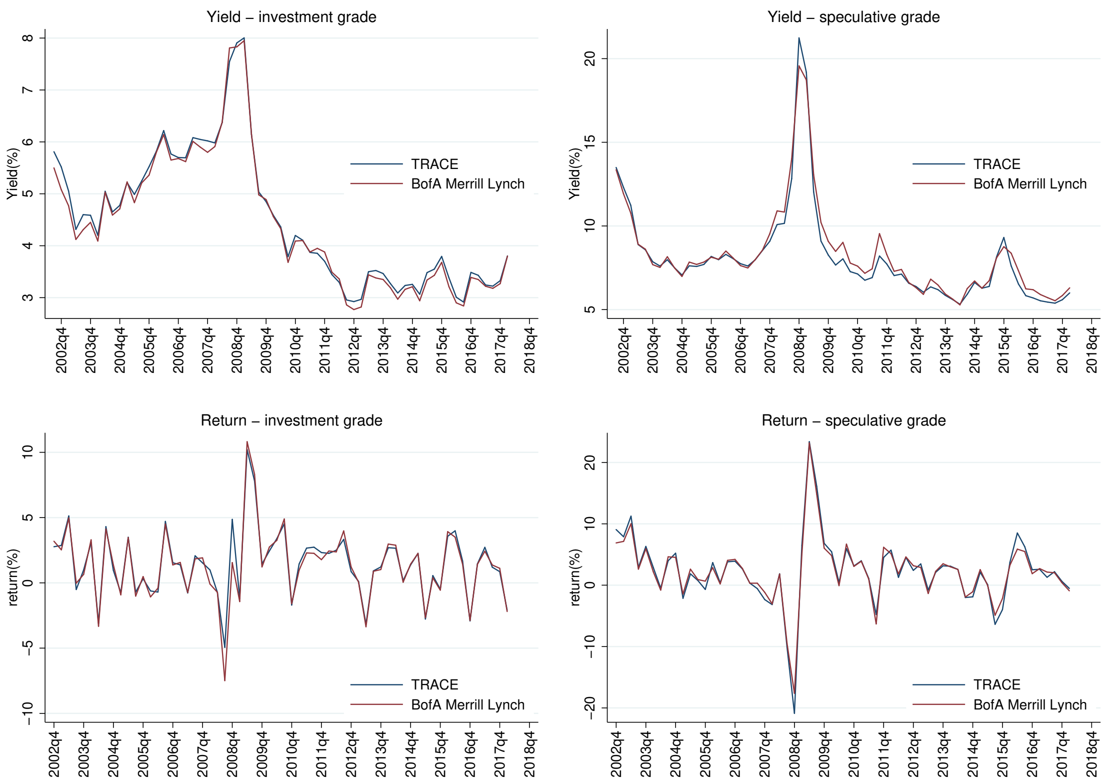
[10] Specifically,

$$r_{i,t} = \frac{P_{i,t} + AI_{i,t} + C_{i,t}}{P_{i,t-1} + AI_{i,t-1}} - 1, \tag{1}$$

where $P_{i,t}$ is bond i's price at the end of quarter/month t, $AI_{i,t}$ is accrued interest, and $C_{i,t}$ is coupon payment, if any, during quarter/month t.

option feature makes returns of convertible and nonconvertible incomparable. Furthermore, I remove bonds with time to maturity less than one year because this criterion is applied to major corporate bond indices such as the Bloomberg Barclays U.S. Corporate Bond Index and the Bank of America (BofA) Merrill Lynch U.S. Corporate Master Index.

Figure II: Corporate bond yields and returns, 2002 to 2018



Notes: For both investment and speculative grade corporate bonds, I compare the average of bond yields calculated based on TRACE transaction prices to BofA Merrill Lynch US Corporate Index Effective Yield. I also compare the average of TRACE bond returns with the return implied by BofA Merrill Lynch Total Bond Return Index Values.

To verify the self-calculated bond yields and returns based on TRACE transaction prices, In Figure II, I compare the average of TRACE bond yields to BofA Merrill Lynch US Corporate Index Effective Yield. I also compare the average of TRACE bond returns to those implied by BofA Merrill Lynch Total Bond Return Index Values. To make the figure concise, I only plot two broad rating groups: investment and speculative grade. The results are similar for more detailed rating and maturity groups. This comparison indicates that my self-complied bond yields and returns using TRACE data are close to BofA bond indices.[11]

4 Detecting hunt-for-duration: The characteristics-based demand model approach

4.1 Empirical specification of demand for bond characteristics

Investors (i.e., life insurers) are indexed by i. Time periods are indexed by t. Bonds are indexed by n. I focus the analysis on the fixed-rate U.S. dollar corporate bonds that are corporate debentures or medium-term notes. Investor i's time t investment in corporate bond n is denoted by $B_{it}(n)$. There is also an outside asset indexed as the zeroth asset, which includes all other bonds (which are not fixed-rate U.S. dollar corporate debentures or medium-term notes) reported on an life insurers' Schedule D Part 1. I use $B_{it}(0)$ to represent all wealth invested in the outside asset by investor i' at time t. Investor i's portfolio weight on corporate bond n at time t is then

$$w_{it}(n) = \frac{B_{it}(n)}{B_{it}(0) + \sum_n B_{it}(n)},$$

and the portfolio weight on the outside asset is

$$w_{it}(0) = 1 - \sum_n w_{it}(n).$$

Investor i's relative demand for corporate bond n at time t, $\delta_{it}(0) = \frac{w_{it}(n)}{w_{it}(0)}$, is modelled

[11] BofA bond indices are available at https://fred.stlouisfed.org/categories/32348?t=baml&ob=pv&od=desc

as

$$\ln \delta_{it}(0) = c_{it} + \beta_{0,it} y_t(n) + \beta_{1,it} d_t(n) + \beta_{2,it}^{'} x_t(n) + \epsilon_{it}(n), \tag{2}$$

where $y_t(n)$ is the yield of bond n at period t over the closest benchmark Treasury bond, $d_t(n)$ is the bond's duration, and $x_t(n)$ stands for bond characteristics including credit rating, issue size, and turnover. Credit rating is the numerical rating converted from the letter rating discussed in Section 3. Bond issue size is measured by the log of total par amount outstanding. Turnover, as a measure of liquidity, is the total trading volume over the current period scaled by par amount outstanding. The error term $\epsilon_{it}(n)$, referred to as the latent demand in Koijen and Yogo (2019), captures investor i's demand for unobserved (by the econometrician) characteristics of bond n at period t.

Equation (2) is referred to as characteristics-based demand because portfolio weights are specified as a function of yield, duration, and other observed and unobserved bond characteristics. Koijen and Yogo (2019) provide a theoretical model for equation (2). There are three key elements in the model. First, investors have mean-variance preferences for returns. Second, returns have a factor structure. Third, expected returns and factor loadings depend on assets' own characteristics.

4.2 Identification strategy with instrument variables

To estimate equation (2), I assume that $\mathbb{E}[\epsilon_{it}(n)|x_t(n)] = 0$, that is, bond rating, size, and turnover are exogenous to latent demand. However, I don't assume that bond yields are orthogonal to latent demand because price-taking may not be credible in the context of life insurance companies who are the largest institutional investors in the U.S. corporate bond market. Higher latent demand can result in higher prices and therefore lower yields. To address the endogeneity of bond yields, I use an instrumental variable strategy similar in spirit to that in Koijen and Yogo (2019).

Construction of the instrumental variable for bond yields relies on defining the investment universe of an investor. Institutions are considered to have an investment universe: They are allowed to hold a subset of bonds issued by a particular group of corporations. The investment universe is practically defined by an investment mandate, which is probably most clearly stated in corporate bond index funds.[12] Insurance companies also have investment mandates, although they are usually not publicly available.[13]

The identification assumption is that each institution's investment universe is exogenous, as it is predetermined by an investment mandate that is exogenous to current demand shocks. Since a bond issuer can have several bond issues outstanding at the same time, I consider the investment universe at the bond issuer (rather than the bond issue) level. When a bond issuer whose bond issues are included in the investment universe of more investors, particularly when those investors are large, it then has a larger exogenous component of demand, which generates higher prices and hence lower yields that are orthogonal to latent demand. Incorporating the above idea into a mathematical expression, the instrument for the yield of bond issued by bond issuer b at time t for estimating investor i's bond demand is specified as

$$\hat{y}_{it}(b) = \log\Big(\sum_{j\neq i} A_{jt}\frac{\mathbf{1}_{jt}(b)}{1+\sum_{m=1}^{B}\mathbf{1}_{jt}(m)}\Big), \tag{3}$$

where A_{jt} is investor j's (other than investor i) time t asset under management (AUM), $\mathbf{1}_{jt}(b)$ is an indicator for whether bond issuer b is in the investment universe of investor j at time t.

4.3 Validity of the instrument

Before estimating the characteristics-based demand equation (2), I conduct several checks for validating the proposed instrument (3).

To verify that institutional investors indeed invest in bonds issued by a fixed subset of

[12]See for example, https://investor.vanguard.com/mutual-funds/profile/VLTCX
[13]https://www.naic.org/capital_markets_archive/110826.htm

bond issuers, i.e., that they have a predetermined investment universe, I tabulate in Table II the percentage of bond issuers whose bonds are held in the current year-end that are ever held in the previous 1 to 3 years. Institutions are separated into groups first by their type and then by their AUM. For life insurance company with median AUM, 83.8% of bond issuers whose bonds are held in current year-end were also in the previous year-end. This indicates that at least 83.8% of bond issuers in the investment universe this year were also part of the investment universe in the previous year. This percentage increases at a very slow pace to 85.0% going 3 years before. The persistence of bond issuers held increases with an institution's size. For life insurer with 90th percentile AUM, 92.3% of bond issuers that are currently held were also held in the previous 3 years. The same patterns also apply to property/casualty (PC) insurance companies and corporate bond mutual funds. Hence, Table II provides supporting evidence consistent with the fact that institutions have investment mandates, as they invest in a relatively fixed subgroup of bond issuers over time. Accordingly, the investment universe for each institution at each date is defined as the subset of bond issuers that are currently or ever held in the portfolio all the way up to the previous 3 years.

The validity of the instrument (3) relies not only on the existence of exogenous investment universe verified above, but also on the variation in the investment universe across the investors. The last two columns of Table III show that there is cross-sectional variation in the investment universe, since the institutions have their investment universe concentrated on a small subset of bond issuers. For example, in years 2014 to 2017, life insurers have a median of 186 bond issuers in the investment universe, whereas the 90th percentile includes 559 bond issuers.

The last check is for verifying that the instrument (3) is not a weak instrument. In particular, I calculate the Cragg–Donald F-statistic for equation (2) fitted via generalized method of moments (GMM) with $[y_{it}(n), d_{it}(n)]'$ instrumented by $[\hat{y}_{it}(n), m_{it}(n)]'$, where

Table II: Persistence of the set of bond issuers held in portfolio

Institution	Years	AUM percentile									
		1	2	3	4	5	6	7	8	9	10
Life	1	84.3	83.3	83.3	84.0	83.8	85.0	86.4	88.3	88.1	91.3
	2	84.7	83.9	84.3	84.3	84.7	85.9	87.2	88.9	88.9	91.8
	3	85.3	84.6	84.6	84.8	85.0	86.5	87.7	89.4	89.6	92.3
PC	1	78.9	80.0	78.9	78.6	78.8	79.7	80.4	80.6	81.1	82.8
	2	80.0	80.0	80.0	80.0	80.0	80.0	81.4	81.3	82.1	84.0
	3	80.0	80.5	80.0	80.0	80.6	81.0	82.0	81.9	82.9	84.6
Mutual	1	95.6	94.4	94.4	94.8	94.2	93.4	94.9	94.0	94.4	95.1
	2	96.4	95.0	95.1	95.2	94.9	94.1	95.4	94.7	95.2	95.4
	3	96.6	95.3	95.5	95.8	95.0	94.7	95.7	95.0	95.7	95.7
All	1	80.0	80.0	79.4	80.0	80.5	81.3	81.8	83.1	84.8	87.9
	2	80.3	81.0	80.0	80.6	81.3	82.1	82.5	84.0	85.7	88.8
	3	82.1	82.6	82.2	83.8	84.6	84.9	86.2	88.0	88.4	90.3

Note: This table reports the percentage of bond issuers held in the current year-end that were ever held in the previous 1, 2, and 3 years. Each cell corresponds to a pooled median across time in an AUM percentile of an institution type. The sample period is from 2002 to 2017.

$m_{it}(n)$ is years to maturity. $m_{it}(n)$ is added for identification purpose, since $d_{it}(n)$ is also endogenous through $y_{it}(n)$. Based on the results in Table II, in calculating the instrument (3), the aggregation is over institutions with at 85% of currently held bond issuers also on the portfolio in the previous 3 years.

As shown in Table III, institutions hold a relatively small number of bonds on their portfolio. Estimation based on the cross-sectional holdings of an individual institution might not be accurate. Therefore, the estimation scheme is that whenever there are more than 1000 holdings in the cross section, I estimate by the individual institution. For institutions with less than 1000 holdings, I pool them together with those that share similarity in regulatory constraints. Specifically, I group the life insurance companies by the A.M. Best's financial strength rating (FSR)[14] and then by the A.M. Best's capital adequacy ratio (BCAR) relative

[14]FSR provides an opinion of an insurer's financial strength and ability to meet its ongoing obligations to policyholders. The scale of FSR ranges from A++ to D, which corresponds to superior to poor financial strength. See http://www.ambest.com/ratings/guide.pdf for FSR category definitions.

Table III: Summary of institutions

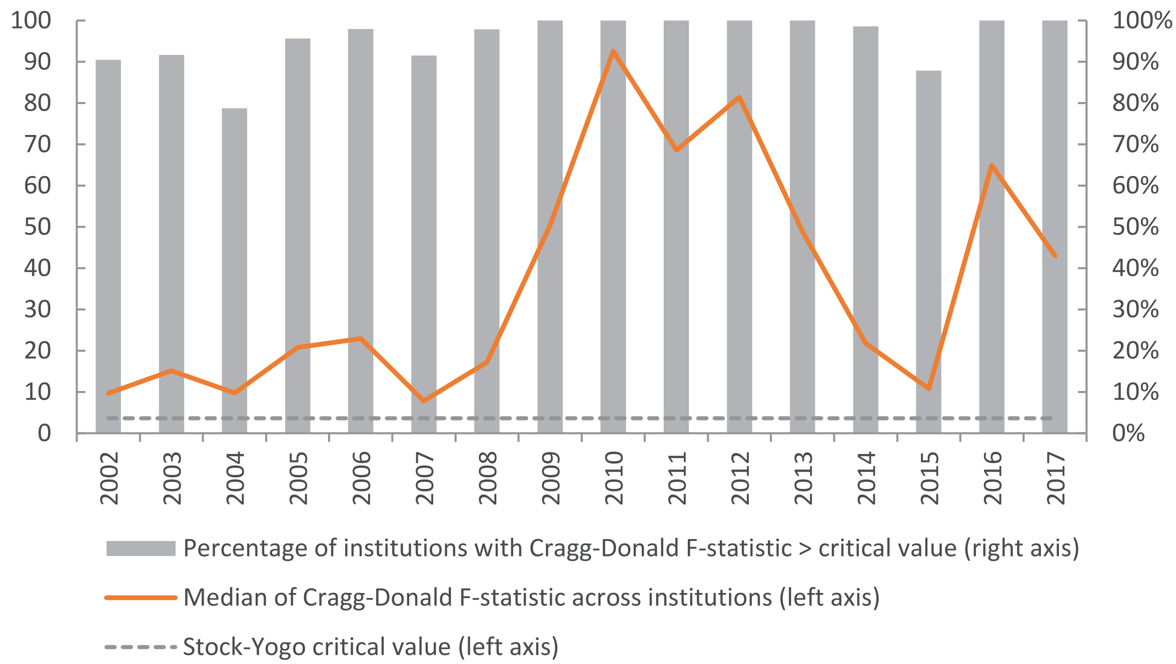
				AUM ($ million)		Number of bonds held		Number of bond issuers in investment universe	
Institution	Period	Number of Institutions	Market share held (%)	Median	90th percentile	Median	90th percentile	Median	90th percentile
Life	2002-2006	682	29	270	6359	86	431	126	461
	2007-2009	595	23	315	7330	95	513	132	490
	2010-2013	565	24	409	9553	124	625	160	523
	2014-2017	533	20	455	11610	150	748	186	559
PC	2002-2006	1427	5	80	902	22	100	41	143
	2007-2009	1479	4	86	1047	23	96	39	138
	2010-2013	1614	5	87	1100	33	132	52	167
	2014-2017	1603	4	88	1100	40	170	66	203
Mutual	2002-2006	444	5	226	1545	86	226	142	303
	2007-2009	401	4	261	1862	103	240	173	324
	2010-2013	365	5	445	2758	118	310	207	361
	2014-2017	369	4	449	3530	119	332	190	357
All	2002-2006	2552	39	128	1847	37	214	66	289
	2007-2009	2475	31	139	1994	39	221	63	290
	2010-2013	2544	34	146	2385	52	279	79	315
	2014-2017	2504	28	149	2805	62	329	96	342

Note: This table reports the time-series mean of each summary statistics within the given period. The sample period is from 2002 to 2017. While the Schedule D data cover all life and PC insurance companies, the data collected from Morningstar for mutual funds include only those classified as corporate bond mutual fund by Morningstar. It's about 1/3 of the number of mutual funds in the literature (e.g., Choi and Kronlund (2017)) that uses a broader classification rule for bond mutual funds.

to the guideline for the current FSR.[15]

Figure III reports, at each date, the median F-statistics across all life insurance companies and the percentage of the pooled estimations with F-statistics above the critical value of 3.63 for rejecting the null of weak instrument listed in Table 5.2 of Stock and Yogo (2005). For a majority of the estimations over the sample period, the null hypothesis of weak instrument is rejected at the 5% significance level.

Figure III: Cragg-Donald F-statistics on the instrument for bond yield



Notes: This figure plots the median Cragg-Donald F-statistics across all life insurance companies and the percentage of the pooled estimations with F-statistics above the critical value of 3.63 for rejecting the null of weak instrument listed in Table 5.2 of Stock and Yogo (2005).

[15]BCAR is the ratio of total adjusted capital to required risk-based capital, where both the available capital and the required capital are computed using A.M. Best's formula. Insurance companies with higher BCAR are considered to be better capitalized. See http://www.ambest.com/ratings/bcar_lh.pdf for details on how BCAR is calculated. The BCAR guideline for each FSR is listed in http://www3.ambest.com/ambv/ratingmethodology/openpdf.aspx?ubcr=1&ri=1112

4.4 Estimated demand for bond duration and other characteristics

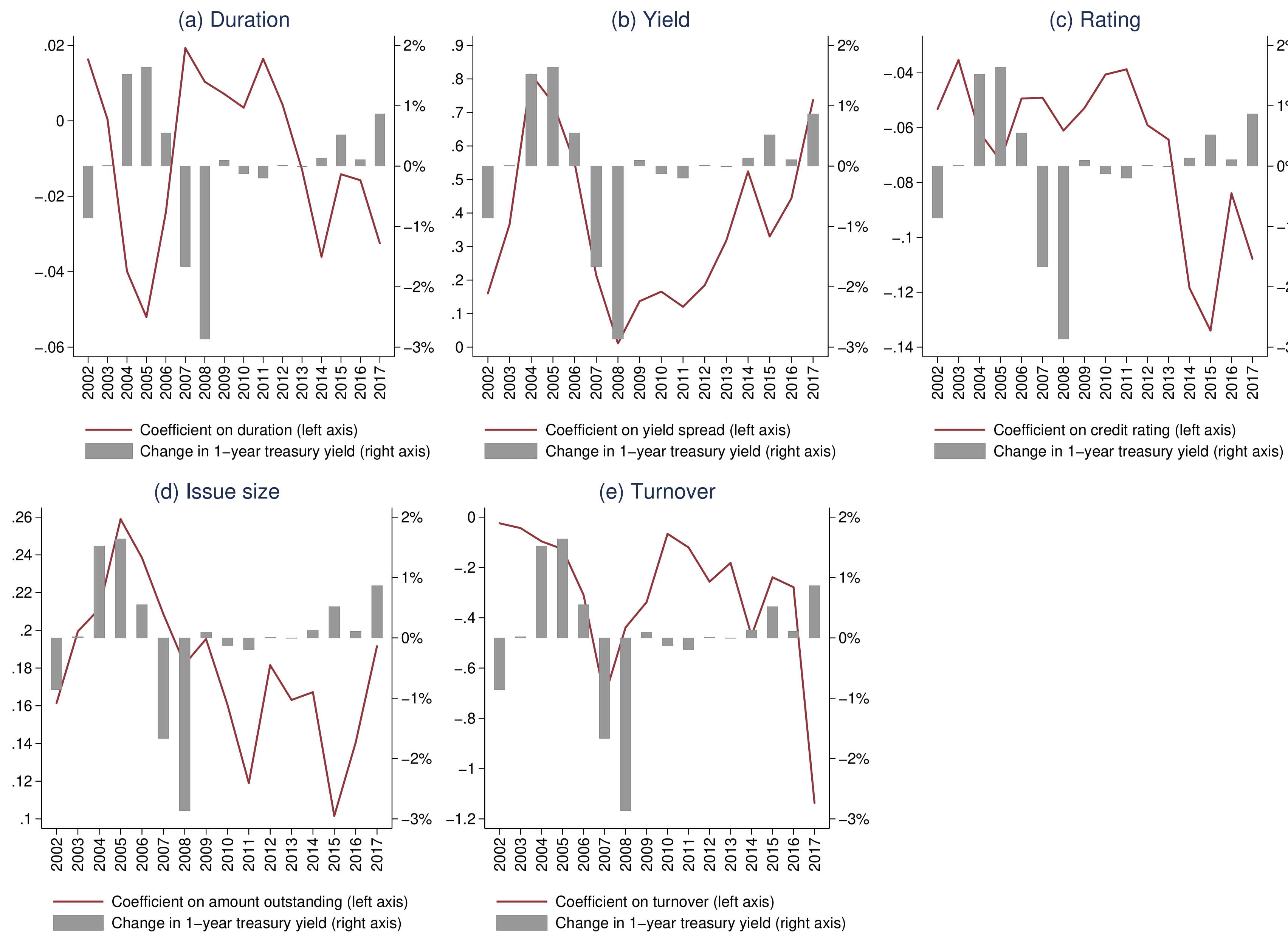
Figure IV provides a summary of the estimated coefficients of life insurance companies' characteristics-based demand equation (2) fitted via generalized method of moments (GMM) with $[y_{it}(n), d_{it}(n)]'$ instrumented by $[\hat{y}_{it}(n), m_{it}(n)]'$. Each panel of Figure IV plots, against the change in 1-year Treasury yield, the average of the estimated coefficient on a bond characteristics across life insurers weighted by their AUM.

Life insurers' demand for duration is captured in Panel (a) of Figure IV. A positive and larger coefficient on duration indicates a heavier tilt in the portfolio towards bonds with higher duration. I observe that hunt-for-duration coincides with episodes of low interest rates. With the 1-year Treasury yield dropping to a historical low as the 2007-2008 financial crisis unfolds, life insurers are tilting their portfolios towards bonds with higher duration. Therefore, this finding is consonant with what's discussed in Section 2.2, that is, life insurers have heightened needs for duration-matching as the interest rate falls to very low point.

Panel (b) of Figure IV depicts life insurers' demand for yield spread. A positive and larger coefficient implies a stronger tilt in the portfolio towards bonds with higher yield spread. Notice that higher demand for yield spread is concurrent with periods of high interest rates. In the pre-crisis period over 2004 to 2006 when interest rates are high and the post-crisis period since 2014 when the interest rates gradually increase after the Federal Reserve (the Fed) tapers Quantitative Easing (QE), life insurers shift their portfolios towards bonds with higher yield spread. This finding is in line with the procyclical pattern in reaching for yield among life insurers found by Becker and Ivashina (2015).

Life insurers' demand for other characteristics, including credit rating, size, and liquidity, are shown in the rest panels of Figure IV, respectively. The findings are in agreement with life insurers' institutional features discussed in Section 2.1. Consistent with the RBC

Figure IV: Coefficients on bond characteristics



Notes: This figure plots, against the change in 1-year Treasury yield, the estimated coefficients of life insurance companies'characteristics-based demand equation (2) fitted via generalized method of moments (GMM) with $[y_{it}(n), d_{it}(n)]'$ instrumented by $[\hat{y}_{it}(n), m_{it}(n)]'$. Each panel corresponds to the average of the estimated coefficient on a bond characteristics across life insurers weighted by their AUM.

requirements, life insurers demand bonds with better credit rating.[16] Life insurers exhibit tolerance for illiquidity,[17] which is compatible with their long-term liability structure.

Table IV: Life insurers' demand for duration and the interest rates

Dep. Var: Coefficient on duration from characteristics-based demand model				
	[1]	[2]	[3]	[4]
ΔTY1	-0.005*	-0.005**	-	-
	[0.002]	[0.002]	-	-
Low	-	0.011***	-	0.006*
	-	[0.003]	-	[0.003]
ΔTY1 × Low	-	-0.014**	-	-
	-	[0.006]	-	-
Δ(TY30 - TY1)	-	-	0.004**	0.007***
	-	-	[0.002]	[0.001]
Δ(TY30 - TY1) × Low	-	-	-	-0.006**
	-	-	-	[0.002]
Insurer FE	Yes	Yes	Yes	Yes
N	7688	7688	7688	7688
R^2	0.18	0.19	0.18	0.18

Notes: This table reports the relationship between life insurers' demand for duration and the interest rates. The dependent variable is the coefficient on duration estimated from the characteristics-based demand equation (2). $\Delta TY1$ is the change in 1-year Treasury yield from year-end $t-1$ to year-end t. $\Delta(TY30-TY1)$ is the change in the difference between 30-year and 1-year Treasury yields from year-end $t-1$ to year-end t. *Low* is an indicator variable that equals one when the Federal funds rate is smaller than or equal to 1%, and zero otherwise. All regressions include insurer fixed effects. Standard errors clustered at the year level are reported in brackets. The symbols ***, **, and * indicate significance levels at 1%, 5%, and 10%, respectively.

Table IV examines in further details the loadings on duration with respect to interest rates. In particular, I regress the coefficient on duration estimated from the characteristics-

[16] As defined in Section 3, a higher numerical rating corresponds to a lower letter rating. Therefore, the negative coefficient on rating implies that life insurers demand bonds with better credit ratings.

[17] Higher turnover indicates greater liquidity. Hence, the negative coefficient on turnover indicate that life insurers demand less liquidity.

based demand equation (2) on interest rate variables including change in the level (1-year Treasury yield, $\Delta TY1$) and slope (30-year minus 1-year Treasury yield, $\Delta(TY30 - TY1)$) of the term structure. Each observation corresponds to one life insurer and year. All regressions include insurer fixed effects. Column 1 confirms that hunt-for-duration is stronger when the interest rate level drops. As shown in column 3, tilt toward high duration is heavier when the slope of yield curve is steeper. To further investigate whether there is asymmetry in the intensity of hunt-for-duration between the high and low interest rate regimes, I create an indicator variable *Low* that equals one when the Federal funds rate is smaller than or equal to 1%, and zero otherwise. Column 3 shows that hunt-for-duration is more sensitive to change in the level of interest rate in the low-rate regime, which is indicated by the negative and significant coefficient on the interaction term $\Delta TY1 \times Low$.

5 Detecting hunt-for-duration: The excess duration approach

5.1 Measure of excess duration

In this section, I provide a measure of hunt-for-duration. In a similar spirit as Ozdagli and Wang (2019) and Choi and Kronlund (2018), the extent to which life insurance companies engage in hunt-for-duration is measured by excess duration. Within each NAIC rating class,[18] the excess duration of the life insurance sector i in quarter t, $ED_{i,t}$, is calculated as the weighted average duration of all corporate bonds held by the life insurance sector minus

[18] There are six NAIC rating class: NAIC 1 to NAIC 6. Throughout the paper, I focus on bonds in NAIC 1 (rated AAA/AA/A) and NAIC 2 (rated BBB) because around 95% of life insurers' bond holdings are investment-grade. At the end of year 2018, life insurance companies hold 65.1% of their bonds in NAIC 1 and 29.8% in NAIC 2, according to Chart 4 of https://www.naic.org/capital_markets_archive/special_report_190725.pdf

the weighted average duration of all corporate bonds outstanding in the market. That is,

$$ED_{i,t} = \sum_j w^i_{j,t} D_{j,t} - \sum_j w^m_{j,t} D_{j,t}, \tag{4}$$

where $D_{j,t}$ is the modified duration of bond j, $w^i_{j,t} = \frac{A^i_{j,t}}{\sum_j A^i_{j,t}}$ with $A^i_{j,t}$ being the amount of bond j held by the life insurance sector, and $w^m_{j,t} = \frac{A^m_{j,t}}{\sum_j A^m_{j,t}}$ with $A^m_{j,t}$ being the total amount of bond j outstanding in the market. Given that excess duration is computed in relative terms, it represents how much life insurers tilt their portfolios away from the market benchmark. In line with Choi and Kronlund (2018), netting out the market benchmark controls for the time-series variation in the aggregate supply of the corporate bonds. Suppose more firms issue bonds with longer maturities in some years, then the increase in hunt-for-duration would only be mechanical if market duration were not taken into account.

For later analysis at the individual bond level, I also define the excess duration for bond j as the following:

$$ED_{j,t} = D_{j,t} - \sum_k w^m_{k,t} D_{k,t}, \tag{5}$$

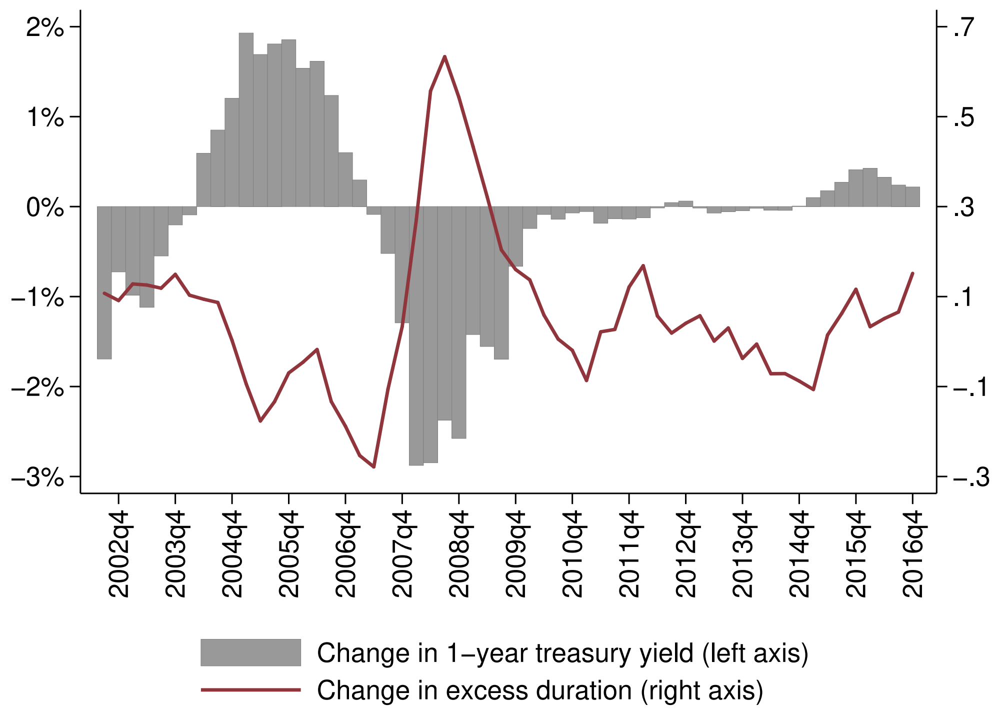
where $D_{j,t}$ is the duration of bond j and $\sum_k w^m_{k,t} D_{k,t}$ is the weighted average duration of all outstanding corporate bonds in the same NAIC rating class as bond j.

5.2 Hunt-for-duration over time

As discussed in Section 2.2, the primary implication of duration-matching is that life insurers hunt for duration to hedge against interest rate risk when the interest rates decline. Figure V presents a first look at this implication. In Figure V, I plot the time series of change in the excess duration of life insurance sector's bond portfolio against the change in 1-year Treasury yield, which serves as the policy indicator in Gertler and Karadi (2015). The bar represents the cumulative change in 1-year Treasury yield from quarter $t-4$ to t. The line traces the cumulative change in excess duration of the life insurance sector from quarter t to

$t+4$. Figure V indicates a negative correlation between change in interest rate and duration adjustment of life insurers.

Figure V: Excess duration of life insurers' bond portfolio and the interest rates



Notes: This figure presents the time series of change in the excess duration of life insurance sector's corporate bond holdings of NAIC1 rating group (rating AAA to A-) (right axis) and the change in 1-year Treasury yield from quarter $t-4$ to quarter t (left axis). The excess duration of life insurance sector's portfolio of bonds within a given rating group is computed as the weighted average duration of all corporate bonds held by the whole life insurance sector less the benchmark duration, which is the weighted average duration of all corporate bonds outstanding in the market within the same rating group. The excess duration measure is defined formally in equation (4).

Formally, I examine the dynamics of excess duration following a change in the interest rate using the differenced regressions:

$$ED_{i,t+k} - ED_{i,t} = \alpha_k + \beta_k(r_t - r_{t-1}) + \Delta\epsilon_{t+k}, \tag{6}$$

where $r_t - r_{t-1}$ is the change in 1-year Treasury yield from quarter $t-1$ to t, and $ED_{i,t+k} - ED_{i,t}$ represents the cumulative change in the excess duration of the life insurers' bond portfolio over the period from quarter t to $t+k$ with $k = 1, \ldots, 16$. Hence, the regressions specified in equation (6) explore how life insurers adjust the duration of their corporate bond portfolios in response not to the level of interest rate, but instead to a recent change in the interest rate. As it is not likely that an innovation in interest rate is met with full response immediately, I allow the horizon on the left hand side to be up to 16 quarters.

Results in Columns [1] and [2] of Table V shows that the portfolio duration of life insurers responds gradually to interest rate changes. When the differencing horizon on the left hand side is less that 4 quarters, the estimates of β_k are small and statistically weak. As the horizon is widened to 4 quarters and beyond, the results become progressively stronger. When the window expands to 11 quarters, $\beta_1 1$ is estimated to be -0.59 with significance level at 1%. This suggests that a 1% decrease in the interest rate leads to a cumulative increase of 0.59 in the excess duration of life insurers' bond portfolio over the next 11 quarters.

To further identify the impact of monetary policy surprises on the duration adjustment of life insurers' bond portfolio , I re-estimate equation (6) using surprises in the three month ahead federal funds futures (denoted as FF4 in Gertler and Karadi (2015)) as an instrument for the change in 1-year Treasury yield. This instrument choice is based on the strong performance of the variable FF4 as an external instrument in the analysis of Gertler and Karadi (2015). Similar to papers that employ intraday measures of monetary policy surprises (e.g., Kuttner (2001), Bernanke and Kuttner (2005) and Gurkaynak et.al. (2005)), surprises in FF4 are measured within a tight window of 30 minutes of the FOMC announcement to ensure that the surprises in futures rates solely reflect news about the FOMC decision.

One issue is that the frequency of the quarterly snapshots of the duration of life insurers' bond portfolio does not align with the uneven number of days between the FOMC meetings. To address this issue, I turn monetary surprises on FOMC days into quarterly average

Table V: Life insurers: Dynamics of portfolio duration following a change in interest rate

Dep. Var: Cumulative change in excess duration of bond portfolio								
	Quarter-level data				Insurer-quarter level data			
	Rate change		Monetary surprise		Rate change		Monetary surprise	
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	β_k	Std. error	β_k	Std. error	β_k	Std. error	β_k	Std. error
k = 1	-0.00	[0.04]	-0.05	[0.10]	-0.02	[0.02]	-0.08***	[0.01]
k = 2	-0.05	[0.08]	-0.12	[0.16]	-0.06*	[0.03]	-0.20***	[0.02]
k = 3	-0.12	[0.08]	-0.21	[0.15]	-0.09*	[0.05]	-0.29***	[0.03]
k = 4	-0.18***	[0.06]	-0.31**	[0.15]	-0.13**	[0.06]	-0.40***	[0.03]
k = 5	-0.28***	[0.04]	-0.46***	[0.16]	-0.18***	[0.07]	-0.53***	[0.03]
k = 6	-0.39***	[0.03]	-0.58***	[0.16]	-0.23***	[0.07]	-0.64***	[0.04]
k = 7	-0.45***	[0.03]	-0.65***	[0.13]	-0.26***	[0.08]	-0.75***	[0.04]
k = 8	-0.49***	[0.04]	-0.72***	[0.12]	-0.30***	[0.08]	-0.81***	[0.04]
k = 9	-0.54***	[0.04]	-0.79***	[0.11]	-0.33***	[0.08]	-0.85***	[0.04]
k = 10	-0.58***	[0.05]	-0.86***	[0.11]	-0.33***	[0.09]	-0.83***	[0.04]
k = 11	-0.59***	[0.05]	-0.87***	[0.11]	-0.34***	[0.09]	-0.82***	[0.05]
k = 12	-0.56***	[0.06]	-0.80***	[0.10]	-0.32***	[0.09]	-0.75***	[0.05]
k = 13	-0.54***	[0.06]	-0.79***	[0.13]	-0.31***	[0.09]	-0.71***	[0.05]
k = 14	-0.52***	[0.04]	-0.74***	[0.15]	-0.27***	[0.09]	-0.63***	[0.05]
k = 15	-0.47***	[0.04]	-0.72***	[0.16]	-0.25***	[0.08]	-0.55***	[0.05]
k = 16	-0.40***	[0.05]	-0.65***	[0.17]	-0.21***	[0.08]	-0.47***	[0.05]
Insurer FE	-	-	-	-	Yes	-	Yes	-

Notes: This table reports regression results from equation (6):

$$ED_{i,t+k} - ED_{i,t} = \alpha_k + \beta_k(r_t - r_{t-1}) + \Delta\epsilon_{t+k},$$

where the dependent variable is the cumulative change in excess duration of life insurers' NAIC1 (rating AAA to A-) bond portfolio for horizons $k = 1, \cdots, 16$ quarters. The independent variable in Columns [1] and [5] is the quarterly change in 1-year Treasury yield. The independent variable in Column [3] and [7] is the quarterly change in 1-year Treasury yield instrumented by quarterly average surprises in the three month ahead federal funds futures (denoted as FF4 in Gertler and Karadi (2015)). Newey-West standard errors allowing for $1.5 \times k$ quarters of lags are reported in brackets in Columns [2], [4], [6], and [8] . The symbols ***, **, and * indicate significance levels at 1%, 5%, and 10%, respectively.

surprises by following the procedure described in footnote 11 of Gertler and Karadi (2015). The calculation is done in three steps. First, I create a cumulative daily surprise series by accumulating all FOMC day surprises. Second, I take quarterly averages of the series. Finally, quarterly average surprises are obtained by taking the first difference of this series.

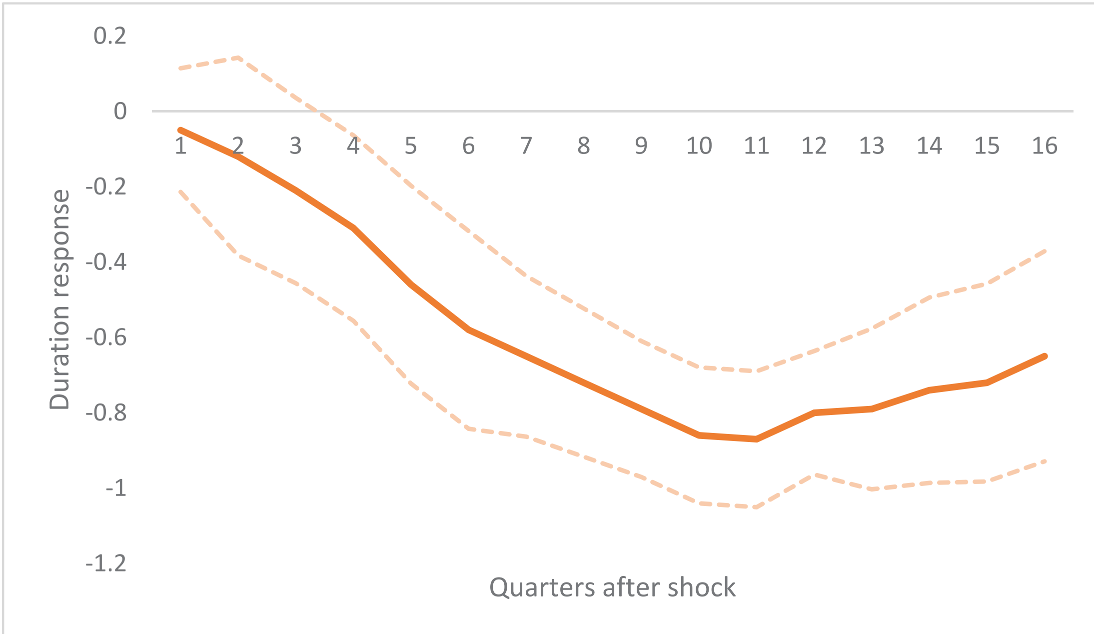
The dynamics of life insurers' bond portfolio duration following a monetary policy shock are reported in Columns[3] and [4] of Table V and also visualized in Figure VI. The F-statistic of the first stage regression of quarterly change in 1-year Treasury yield on quarterly average of FF4 surprise is 10.46, which is above the threshold of 10 proposed in Stock et al. (2001). This implies that the problem of weak instrument is absent. Over the 11 quarters following a 1% expansionary monetary policy surprise, the excess duration of life insurers' bond portfolio increase by 0.89.

5.3 Comparison with mutual funds

To illustrate that hunt-for-duration is unique to life insurance companies due to their liability-driven portfolio management, I use other major bond investors as a comparison group as in Domannski et al. (2017) and Ozdagli and Zhang (2017). In particular, I compare and contrast the evolution of bond portfolio duration of life insurers with that of mutual funds, who are the second largest participants in the corporate bond market. Different from life insurers, the investment strategies of mutual funds are asset-driven. Mutual fund managers have strong incentive to achieve high performance to beat their peers, since investor flows into and out of mutual funds are strongly linked to their past performance (Coval and Stafford, 2007, Goldstein, Jiang, and Ng 2017). Hence, mutual funds, who are subject to short-term performance monitoring, are more likely to be averse to holding long-term bonds whose prices are volatile as the interest rates fluctuate.

I re-examine equation (6) in Section 5.2 by replacing the dependent variable with the excess duration of the mutual fund sector. Table VI and Figure VII present the results. In

Figure VI: Life insurers: Response of excess duration to monetary policy surprises



Notes: This figure plots the coefficient β_k from estimating equation (6):

$$ED_{i,t+k} - ED_{i,t} = \alpha_k + \beta_k(r_t - r_{t-1}) + \Delta\epsilon_{t+k},$$

where the dependent variable is the cumulative change in excess duration of life insurance sector's NAIC1 bond portfolio for horizons $k = 1, \cdots, 16$ quarters. The independent variable is the quarterly change in 1-year Treasury yield instrumented by quarterly average surprises in the three month ahead federal funds futures (denoted as FF4 in Gertler and Karadi (2015). Confidence intervals based on Newey-West standard errors allowing for $1.5 \times k$ quarters of lags are shown as dashed lines.

the one quarter after a 1% surprise decline in the monetary policy rate, mutual funds cut the excess duration by 0.22. Over the following 8 quarters, I find a cumulative decrease of 1.1 in mutual funds' excess duration.

The results above indicate that mutual funds, in contrast with life insurers, are shifting their corporate bond portfolios toward lower duration as the interest rates decrease. Therefore, this comparison confirms that hunt-for-duration is not a general feature in the corporate bond market when the interest rates are low, but a specific one accounted for by the duration-matching portfolio management strategy of life insurance companies.

Table VI: Mutual funds: Dynamics of portfolio duration following a change in interest rate

Dep. Var: Cumulative change in excess duration of bond portfolio				
	Rate change		Monetary surprise	
	[1]	[2]	[3]	[4]
	β_k	Std. error	β_k	Std. error
k = 1	0.13***	[0.04]	0.22*	[0.13]
k = 2	0.23**	[0.09]	0.47*	[0.26]
k = 3	0.26***	[0.07]	0.40**	[0.18]
k = 4	0.34***	[0.09]	0.60**	[0.28]
k = 5	0.38***	[0.09]	0.57**	[0.22]
k = 6	0.41***	[0.06]	0.85***	[0.27]
k = 7	0.50***	[0.06]	0.94***	[0.29]
k = 8	0.55***	[0.05]	1.10***	[0.34]
k = 9	0.58***	[0.07]	1.20***	[0.37]
k = 10	0.65***	[0.12]	1.31***	[0.42]
k = 11	0.68***	[0.14]	1.38***	[0.50]
k = 12	0.63***	[0.15]	1.41***	[0.52]
k = 13	0.59***	[0.17]	1.34**	[0.50]
k = 14	0.65***	[0.19]	1.65***	[0.59]
k = 15	0.67**	[0.25]	1.56***	[0.57]
k = 16	0.59**	[0.24]	1.56***	[0.56]

Notes: This table reports regression results from equation (6):

$$ED_{i,t+k} - ED_{i,t} = \alpha_k + \beta_k(r_t - r_{t-1}) + \Delta\epsilon_{t+k},$$

where the dependent variable is the cumulative change in excess duration of mutual fund sector's NAIC1 bond portfolio for horizons $k = 1, \cdots, 16$ quarters. The independent variable in Column [1] is the quarterly change in 1-year Treasury yield. The independent variable in Column [3] is the quarterly change in 1-year Treasury yield instrumented by quarterly average surprises in the three month ahead federal funds futures (denoted as FF4 in Gertler and Karadi (2015). Newey-West standard errors allowing for $1.5 \times k$ quarters of lags are reported in brackets in Columns [2] and [4] . The symbols ***, **, and * indicate significance levels at 1%, 5%, and 10%, respectively.

Figure VII: Mutual funds: Response of portfolio duration to monetary policy surprises

Notes: This figure plots the coefficient β_k from estimating equation (6):

$$ED_{i,t+k} - ED_{i,t} = \alpha_k + \beta_k(r_t - r_{t-1}) + \Delta\epsilon_{t+k},$$

where the dependent variable is the cumulative change in excess duration of mutual fund sector's NAIC1 bond portfolio for horizons $k = 1, \cdots, 16$ quarters. The independent variable is the quarterly change in 1-year Treasury yield instrumented by quarterly average surprises in the three month ahead federal funds futures (denoted as FF4 in Gertler and Karadi (2015). Confidence intervals based on Newey-West standard errors allowing for $1.5 \times k$ quarters of lags are shown as dashed lines.

5.4 Interaction between life insurance companies and mutual funds

In the previous sections, I have shown that while the excess duration of life insurers' bond portfolio rises in the low interest rate environment, the excess duration mutual funds' bond portfolio declines. In this section, I further look into the potential trading interactions between life insurance companies and mutual funds. In particular, when mutual funds sell (buy) bonds with duration higher (lower) than the market benchmark, are life insurance companies on the other side of the trade? To answer this question, I estimate the following regression similar to Cai et al. (2019):

$$NT^I_{j,t} = \beta_0 + \beta_1 \cdot NT^M_{j,t} + \beta_2 \cdot Above_{j,t} + \beta_3 \cdot NT^M_{j,t} \times Above_{j,t} + \epsilon_{j,t}, \tag{7}$$

where in quarter t, $NT^I_{j,t}$ and $NT^M_{j,t}$ are the net amount of bond j traded by all life insurance companies and mutual funds, respectively. For example, $NT^M_{j,t} = -100$ ($NT^M_{j,t} = 100$) means that mutual funds, on net, sell (buy) \$100 worth of bond j in quarter t. $Above_{j,t}$ is a dummy variable equal to 1 when the duration of bond j is above the market benchmark. δ_t is the quarter fixed effect. The standard errors are clustered at the bond issuer level.

The regression specified in equation (7) is estimated separately for two cases where (1) mutual funds are the net seller of a bond with $NT^M_{j,t} < 0$, and (2) mutual funds are the net buyer of a bond with $NT^M_{j,t} > 0$. The sample is divided into the high (before 2009Q1) and the low (after 2009Q1) interest rate period. As in Maggio and Kacperczyk (2017), the split of the high and low interest rate period is based on the 1% of the interest rate level.

Columns [1] and [2] of Table VII report the regression results for bonds that are on net sold by mutual funds. During the high interest rate period, the estimated coefficient on $NT^M_{j,t}$ in Column [1] is -0.12. The interpretation is that \$100 more sales of a bond with negative excess duration by mutual funds is associated with \$12 more purchases by life insurers. However, as indicated by the insignificant estimate of the interaction term $NT^M_{j,t} \times Above_{j,t}$, the correlation between mutual funds' sales and life insurers' purchases is not notably stronger for bonds with positive excess duration.

Over the low interest rate period, as reported in Column [2], the coefficient on $NT^M_{j,t}$ is -0.06, so that each additional \$100 of sales by mutual funds of a bond with duration lower than the market benchmark is associated with \$6 of more purchases by life insurance companies. The negative and significant coefficient of -0.29 on the interaction term $NT^M_{j,t} \times Above_{j,t}$ indicates that when a bond with positive excess duration is on net sold by mutual funds, it is more likely to be bought by life insurers. Specifically, for bonds with duration higher than the market benchmark, each additional \$100 of sales by mutual funds is associated with \$35 (= -(-0.06-0.29)$\times$100) more purchases by life insurance companies. The result suggests that compared to bonds with negative excess duration, the correlation between mutual funds' sales and life insurers' purchases is around six times stronger for bonds with positive excess duration.

The results for bonds which mutual funds on net buy are presented in columns [3] and [4] of Table VII. The bonds are restricted to those purchased from the secondary market Primary market trading will be studied in detail in a later section. For a bond with duration above the market benchmark, \$100 more purchases of that bond by mutual funds is associated with \$6 (= -(-0.20 + 0.14)$\times$100) more sales by life insurers in the high interest rate environment. However, in the low interest rate environment, the trading dynamics of bonds with positive excess duration between mutual funds and life insurers reverses: \$100 more purchases of a bond with duration above the market benchmark by mutual funds is associated with \$15 (= (-0.05 + 0.20)$\times$100) more purchases by life insurers.

In summary, the results in Table VII confirm that life insurers and mutual funds are trading on the opposite side. This is particularly true during times of low interest rates when life insurers acquire a substantial fraction of the bonds with duration above the market benchmark sold by mutual funds.

5.5 Hunt-for-duration in the cross-section

Up to this point, all analyses are conducted at the aggregate level of the entire life insurance sector. In this section, I explore the cross-sectional differences across individual life insurance companies. In particular, I investigate how hunt-for-duration behaviour is connected with certain company characteristics of life insurers. The characteristics of interest are regulatory constraints, leverage ratio, company size, and organization type.

Table VII: Interactive trading between life insurance companies and mutual funds

Dep. Var.: Life insurer net trade	Mutual fund net trade < 0		Mutual fund net trade > 0	
	[1]	[2]	[3]	[4]
	High rate	Low rate	High rate	Low rate
Mutual fund net trade	-0.12*	-0.06***	-0.20***	-0.05***
	[0.06]	[0.02]	[0.05]	[0.02]
Mutual fund net trade × Above	-0.18	-0.29***	0.14*	0.20**
	[0.12]	[0.04]	[0.08]	[0.09]
Quarter FE	Yes	Yes	Yes	Yes
N	21066	52012	23409	31735
R^2	0.04	0.08	0.04	0.03

Notes: This table reports regression results on the interactive trading between between mutual funds and life insurance companies in the high- (before 2009Q1) and low-interest rate(after 2009Q1) regime. The regime split is based on 1-year Treasury yield level of 1%. The dependent variable is life insurance sector's net trading amount of bond j in quarter t. The regressions are separated into cases where the mutual fund sector on net sell (Columns [1] and [2]) or buy (Columns [3] and [4]) a particular bond in a quarter. The independent variables include mutual fund sector's net trading amount of bond j in quarter t, a dummy variable *Above* which equals one when bond j in quarter t has duration above the market benchmark (i.e., positive excess duration), and the interaction term between net trade and the dummy *Above*. Retiring bonds (with amount outstanding reduced by more than 50% due to calls, maturity, conversion, etc.) are excluded. Standard errors reported in brackets are clustered at the bond issuer level. The symbols ***, **, and * indicate significance levels at 1%, 5%, and 10%, respectively.

The extent to which each life insurance company engages in hunt-for-duration is captured by the excess duration of its bond portfolio. Regulatory constraint is measured by A.M. Best's capital adequacy ratio (BCAR). BCAR is the ratio of total adjusted capital to required risk-based capital. The required risk-based capital specifies the amount of capital needed for a life insurance company to survive the risks inherent in its operations. The required risk-based capital is computed based on A.M. Best's formula which takes into account four broad risk categories that life insurers face.[19] The capital requirement component that is

[19] According to A.M. Best (2016), the four categories of risk are asset risk, insurance risk, interest-rate risk, and business risk. The total required risk-based capital is obtained by adding up the capital requirement for each risk category with a "square root rule" covariance calculation, thereby rewarding diversification across

the most relevant to hunt-for-duration is on the interest risk. Charges on the interest risk penalize a mismatch between a life insurer's liability and asset cash flows, thereby restricting the the risk of losses due to interest rate fluctuations. A higher BCAR means that the life insurer is better capitalized.

The hypothesis is that more regulatory-constrained life insurers tend to hunt for duration more; and during times of low interest rates, the connection between regulatory constraint and hunt-for-duration is even stronger. To test this hypothesis, I estimate the following regression model:

$$ED_{i,t} = \beta_0 + \beta_1 \cdot BCAR_{i,t-1} + \beta_2 \cdot Low_t + \beta_3 \cdot BCAR_{i,t-1} \times Low_t + \gamma^{'} X_{i,t-1} + \epsilon_{i,t}, \quad (8)$$

where the dependent variable $ED_{i,t}$ is the excess duration of life insurer i's bond portfolio at quarter t. Low_t is a dummy variable that is equal to one for the period after 2009Q1 when the 1-year Treasury yield is below 1%, and zero otherwise. $BCAR_{i,t-1}$ is lagged A.M. Best's capital adequacy ratio of the year-end before the current quarter t. The vector $X_{i,t-1}$ denotes lagged company characteristics of the year-end before the current quarter t, as well as their interaction terms with the dummy variable Low_t. Additional company characteristics include leverage, company size, and stock dummy, which is equal to one if outside shareholders are co-owners of the company and zero if policyholders are co-owners of the company.[20] The leverage ratio is calculated as one minus the ratio of equity to total assets. Company size is the log of total assets. To account for time-invariant insurer characteristics, I include insurer fixed effects. Year fixed effects are also included to control for general macro trends. Standard errors are clustered at the quarter level. I drop firms with asset value smaller than $1 million or with less than ten bonds on their portfolios in a given quarter.

categories of risks.

[20] For more detailed definition of stock and mutual insurance companies, refer to https://www.investopedia.com/articles/personal-finance/011916/mutual-vs-publically-traded-insurance-companies.asp

Table VIII: Regulatory constraint and hunt-for-duration

Dep. Var: Excess duration of bond portfolio				
	[1]	[2]	[3]	[4]
BCAR	-0.12***	-0.12***	-0.11***	-0.13***
	[0.03]	[0.02]	[0.02]	[0.02]
BCAR × Low	-0.10***	-0.07***	-0.08***	-0.04**
	[0.02]	[0.02]	[0.02]	[0.01]
Leverage	-	-	0.83	-0.01
	-	-	[0.51]	[0.49]
Leverage × Low	-	-	1.31***	1.18***
	-	-	[0.22]	[0.22]
Asset	-	0.32***	-	0.32***
	-	[0.04]	-	[0.04]
Asset × Low	-	0.15***	-	0.13***
	-	[0.02]	-	[0.02]
Stock	-	-0.51***	-0.53***	-0.48***
	-	[0.12]	[0.12]	[0.13]
Stock × Low	-	-0.73***	-0.80***	-0.79***
	-	[0.08]	[0.09]	[0.09]
Insurer FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
N	11208	11208	11208	11208
R^2	0.76	0.77	0.77	0.77

Notes: This table reports results from the panel regression of hunt-for-duration on characteristics of life insurance companies. The observations are at the insurer-quarter level. The dependent variable is the excess duration of a life insurer's portfolio of bonds in NAIC class 1. The independent variables are company characteristics as well as their interaction terms with the dummy variable Low, which is equal to one for the periods after 2009Q1, when the 1-year Treasury yield is below 1%. The company characteristics include BCAR, (log) total assets, leverage ratio, and an indicator for whether a life insurer is a stock company. All company characteristics are lagged values of the year-end prior to the current quarter and are winsorized at the top and bottom 5%. Life insurers with less than ten bonds in their portfolios or with total assets less than $1 million are dropped. All regressions include insurer fixed effects and year fixed effects. Standard errors reported in brackets are clustered at the quarter level. The symbols ***, **, and * indicate significance levels at 1%, 5%, and 10%, respectively.

Column [1] of Table VIII reports a baseline regression of the excess duration of bond portfolio on the BCAR ratio. The negative and significant coefficient on the variable $BCAR$ indicates that a decrease of one in capital adequacy ratio corresponds to a 0.12 increase in the excess duration of bond portfolio over the period of high interest rates. This is consistent with the hypothesis that life insurers that are more regulatory constrained (i.e., with low values of BCAR) hunt for duration more (i.e., have bond portfolios with higher excess duration). Moreover, the coefficient on the interaction term $BCAR \times Low$ equals -0.10 with high significance level, implying that the negative association of hunt-for-duration with BCAR almost doubled during times of low interest rates.

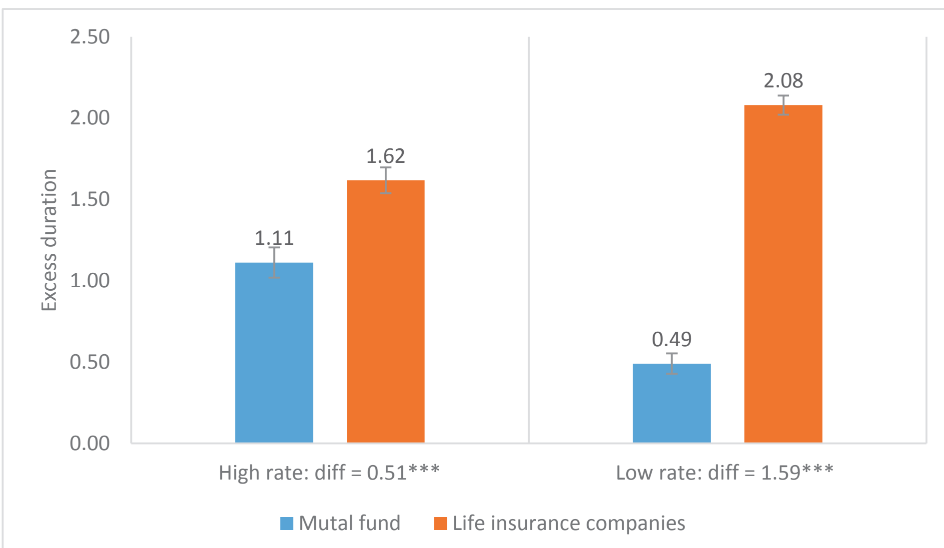
Columns [2] to [4] of Table VIII, I include additional controls: leverage, asset size, and stock company indicator. Hunt-for-duration is more pronounced among life insurers with higher leverage over the period of low interest rates, as the coefficient on the interaction term $Leverage \times Low$ is positive and significant. Also, the positive and significant coefficients on the variable $Asset$ and the interaction term $Asset \times Low$ suggest that larger firms hunt for duration; and appear more so in times of low interest rates. As indicated by the negative and significant coefficient on the variable $Stock$, compared to life insurance companies with mutual ownership, stock life insurers engage less in hunt-for-duration. The dispersion between these two types of life insurers further widens when interest rates are low, as the coefficient on the interaction term $Stock \times Low$ is negative and significant. Above all, the findings regarding regulatory constraint and hunt-for-duration behaviour are robust to controlling for a set of company characteristics. The hypothesis is confirmed that life insurance companies under higher regulatory pressure hunt for duration more, and especially in times of low interest rates.

6 Hunt-for-duration: Evidence from transactions

6.1 Primary market trading

So far, we have focused on the quarter-end snapshots of the excess duration of the bond holdings of the life insurance sector. It is worth noting that according to NAIC Schedule D transaction data, around 40% of life insurers' buy trades take place in the primary market for newly issued bonds. Hence, looking at the investment choices at the time of bond issuance is essential for investigating the hunt-for-duration behaviour among life insurers. Life insurers' holdings of new bonds issued in the primary market are based on acquisitions that occur within a quarter since the offering date.

Figure VIII: Excess duration of newly-issued bonds acquired by life insurers v.s. mutual funds



Notes: This figure compares the value-weighted average excess duration on NAIC2 (rating BBB) corporate bonds acquired by insurance companies and mutual funds. Bars indicate 95% confidence intervals for the average. The differences are reported as compared to life insurers. *** indicate statistical significance at the 1% level.

Figure VIII presents some preliminary evidence for more pronounced hunt-for-duration on the part of life insurance companies in the primary market during times of low interest rate.

Figure VIII contrasts, separately during periods of high and low interest rate, the weighted average of excess duration of new bond issues purchased by life insurance companies and mutual funds. In times of high interest rate, life insurers buy bonds with excess duration, on average, 0.51 higher than mutual funds. The gap increases to 1.59 during times of low interest.

Comparison of the simple mean in Figure VIII doesn't take into account other bond characteristics. One concern is that life insurers are buying bonds with longer duration because those bonds happen to have higher yield spread. To address such concern, I conduct a closer investigation of life insurers' hunt-for-duration behaviour in the primary market by estimating the following regression with controls of bond characteristics:

$$PctInsurer_{j,t} = \beta_0+\beta_1 \cdot ED_{j,t}+\beta_2 \cdot YS_{j,t}+\beta_3 \cdot Low_t+\beta_4 \cdot ED_{j,t}\times Low_t+\beta_5 \cdot YS_{j,t}\times Low_t+\gamma^{'} X_{j,t}+\epsilon_{j,t}. \tag{9}$$

The regression is at the bond level: Each observation corresponds to an individual new bond j issued in quarter t. During the quarter t when bond j is issued, the dependent variable $PctInsurer_{j,t}$ is the percentage of the newly-issued bond j that is acquired by life insurance companies. Similar to Becker and Ivashina (2015), the percentage is calculated using the total amount of bond j acquired by life insurance companies and mutual funds as the denominator. By constructing the dependent variable $PctInsurer_{j,t}$ in this way, life insurers' purchases of newly-issued bonds are measured against mutual funds. As defined in equation (5), $ED_{j,t}$ is the duration of bond j (estimated using offering price and cash flow information from FISD) relative to all outstanding bonds within the same NAIC rating group. $YS_{j,t}$ is bond j's yield (reported in FISD at the time of issuance) over the closest benchmark Treasury bond. Low_t is a dummy variable equal to one for the period of low interest rate after 2009Q1. In addition, issue size is used as a proxy for bond liquidity, following Campbell and Taskler (2003). To control for the possibility that life insurers might prefer one bond credit rating to another, I include bond rating as an another control variable. For brevity, the additional control variables (log of issue size and bond credit rating) as well as their interaction terms with the dummy variable Low_t are denoted by vector $X_{j,t}$. Since NAIC class 1 bonds and NAIC class 2 bonds are subject to different risk-based capital requirements. I estimate equation (9) separately for these two NAIC classes. I cluster the standard errors at the bond issuer dimension to account for the fact that some bond issuers issue several different bonds. Above all, notice that through controlling for bond yield spread, the regression specification (9) can distinguish hunt-for-duration for the purpose of hedging against interest rate risk from reach-for-yield for the purpose of generating higher expected returns.

The results for the regression specification (9) are documented in Table IX. In Columns [1] through [3], the sample includes bonds that belong to NAIC class 1. In Column [1], the positive and significant coefficient on the variable ED indicates that compared with mutual funds, life insurance companies are more prone to purchase new bonds with higher excess duration. Moreover, such propensity is even stronger over the period of low interest rates because the coefficient on the interaction term $ED \times Low$ is positive and significant at the 1% confidence interval. In terms of economic magnitudes, over the period of high interest rates, a one standard deviation of increase in bond excess duration (4.15) corresponds to a 4.98% (=1.20×4.15) increase in life insurers' fraction of holdings of newly-issued bonds. This is 22.47% of the standard deviation of the dependent variable. Moreover, in times of low interest rates, a one standard deviation of increase in the excess duration (4.15) is associated with a 8.63% (= (1.20+0.88)×4.15) increase in the share of life insurance holdings. This is 38.94% of the standard deviation of the dependent variable. As we move from the high interest rate period to the low interest rate period, the effect of bond excess duration on life insurers' acquisitions of bonds at issue becomes almost 75% larger.

As shown in Column [3] of Table IX, the coefficients on the variable ED and the inter-

Table IX: Life insurers: primary market acquisition of newly-issued bonds

Dep. Var: Percentage acquired by life insurers						
	NAIC class 1			NAIC class 2		
	[1]	[2]	[3]	[4]	[5]	[6]
Excess duration (ED)	1.20***	-	1.20***	0.61***	-	0.60***
	[0.17]	-	[0.17]	[0.13]	-	[0.13]
ED× Low	0.88***	-	0.89***	1.86***	-	1.84***
	[0.18]	-	[0.18]	[0.17]	-	[0.17]
Yield spread (YS)	-	-0.69	-0.64	-	-1.57***	-1.55***
	-	[0.68]	[0.60]	-	[0.52]	[0.52]
YS× Low	-	3.51***	0.62	-	3.48***	2.43***
	-	[1.12]	[0.96]	-	[0.82]	[0.71]
Rating	1.09***	1.41***	1.14***	-0.69	-0.58	-0.42
	[0.27]	[0.31]	[0.28]	[0.45]	[0.45]	[0.45]
Rating× Low	-0.62	-0.62	-0.68	-0.38	-1.87**	-0.94
	[0.46]	[0.56]	[0.48]	[0.69]	[0.77]	[0.69]
Issue size	-1.91***	-2.33***	-1.84***	-4.49***	-4.18***	-4.10***
	[0.63]	[0.61]	[0.62]	[0.45]	[0.39]	[0.39]
Issue size× Low	-3.34***	-5.94***	-3.41***	-3.59***	-3.77***	-3.92***
	[0.84]	[0.91]	[0.84]	[0.84]	[0.88]	[0.81]
	5202	5202	5202	4476	4476	4476
R^2	0.24	0.13	0.24	0.29	0.14	0.29

Notes: This table reports results from regression of life insurers' primary market acquisition of newly-issued investment-grade corporate bonds. The dependent variable is life insurers' acquisition of a newly-issued bond as percentage of the bond's total amount acquired by life insurers and mutual funds. The independent variables are bond characteristics as well as their interaction terms with dummy variable *Low*, which equals one for the periods after 2009Q1 when the 1-year Treasury yield is below 1%. Excess duration of a bond is its duration minus market benchmark defined in equation (5). Yield spread is yield to maturity at issuance over the closest benchmark Treasury bond. Issue size is log of offering amount at issuance. Rating is the numerical rating with correspondence with letter rating defined in Section 3. All bond characteristics (except rating) are winsorized at the top and bottom 2.5%. Standard errors reported in brackets are clustered at the bond issuer level. The symbols ***, **, and * indicate significance levels at 1%, 5%, and 10%, respectively.

action term $ED \times Low$ stay robust with controls of bond yield spread, liquidity, and credit rating. One important observation through comparing results in Column [2] with Column [3] is that with inclusion of excess duration, the coefficient on the interaction term $YS \times Low$ drops from significant 3.51 to 0.62, insignificantly different from zero. This implies that life insurers' inclination for buying bonds with higher yield in times of low interest rates is mainly prompted by increasing the duration of their bond portfolio for duration-matching purposes, i.e., hunt-for-duration.

In Columns [4] to [6], I repeat the analysis with the sample of bonds in NAIC rating class 2. The coefficients on the variable ED and the interaction term $ED \times Low$ remain similar without (Column [4]) or with (Column [6]) controlling for the bond yield. According to Column [6], in the low interest rate environment, for a one standard deviation (3.46) increase in the excess duration, life insurers' acquisition of newly-issued bonds is predicted to be 8.44% (=(0.60+1.84)×3.46) higher. This is 43.82% of the standard deviation of the dependant variable. Column [6] further shows that even when controlling for bond excess duration, there are still signs of a positive association between bond yield spread and life insurers' acquisition within NAIC rating class 2 when interest rates are low. However, the economic magnitude is relatively small: A one standard deviation increase in the yield spread (0.86%) corresponds to a 0.76% (=(-1.55+2.43)×0.86) higher share of life insurers' purchases of new bonds from the primary market over the period of low interest rates, This is equivalent to only 3.94% of the dependent variable.

Overall, the results in Table IX suggest that confirm the hypothesis that life insurers tend to load more aggressively on new bonds with higher excess duration during times of low interest rates. Moreover, life insurers' shift, at first glance, towards bonds with higher yields in the low interest rate environment is for the most part brought about by life insurers' hunt-for-duration behaviour. This finding is consistent with that in Ozdagli and Zhang (2019), where they use a matching-procedure to carve out the duration-risk component from the yield of life insurers' bond portfolios.

6.2 Secondary market trading

Purchasing newly-issued bonds from the primary market is not the only way through which life insurance companies can adjust the duration of their corporate bond portfolios. Duration adjustments can also be made through acquiring or disposing seasoned bonds in the secondary market. In this paper, transactions which take place after one or more quarters following the date of bond issuance are defined as trading activities in the secondary market. According to NAIC Schedule D data, life insurers also trade a large amount in the secondary market: Over the sample period from year 2002 to 2017, an average life insurance company buys around 15% and sell 14% of its corporate bond holdings during a year in the secondary market. To investigate whether life insurers engage in hunt-for-duration in the secondary market when interest rates are low, I track the quarterly bond trades of life insurers. Specifically, I estimate the specification of the following form:

$$PctChg_{j,t} = \beta_0 + \beta_1 \cdot ED_{j,t} + \beta_2 \cdot YS_{j,t} + \beta_3 \cdot Low_t + \beta_4 \cdot ED_{j,t} \times Low_t + \beta_5 \cdot YS_{j,t} \times Low_t + \gamma' X_{j,t} + \epsilon_{j,t}. \tag{10}$$

where $PctChg_{j,t}$ denotes the percentage change since quarter $t-1$ in life insurance sector's total holdings of bond j traded by life insurers in quarter t. For secondary market trades, bond duration and yield are estimated using end-of-quarter transaction prices from TRACE and cash flow information from FISD. As defined in equation (5), excess duration $ED_{i,j}$ is the duration of bond j relative to all outstanding bonds within the same NAIC rating group. Yield spread $YS_{j,t}$ is bond j's yield over the closest benchmark Treasury bond. Low_t is a dummy variable equal to one for the periods after 2009Q1, over which the 1-year Treasury yield is below 1%. As defined in Nielson et al. (2012), turnover is used as a measure of bond liquidity. Specifically, bond turnover is computed as log value of total trading volume reported in TRACE in the current quarter divided by the amount outstanding in the previous quarter. NAIC1 is equal to one for bonds that belongs to NAIC1 rating class. The additional control variables as well as their interaction terms with the dummy variable Low_t are denoted by vector $X_{j,t}$. To control for time-varying bond issuer characteristics, I include bond issuer-quarter fixed effects. Since there are bond issuers having more than one bond outstanding at the same time, standard errors are clustered at the bond issuers level in order to allow for potential correlation among the different issues within bond issuers. Retiring bonds (with amount outstanding reduced by more than 50% due to calls, maturity, conversion, etc.) are excluded.

Table X presents the findings for life insurers' trading activities in the secondary market. In Column [1], the coefficient on the variable *ED* is positive and significantly different from zero. This suggests that the quarterly change in the holdings of a bond by life insurers is an increasing function of its excess duration. That is, life insurers acquire more of the bonds with longer duration and sell more of the bonds with shorter duration. On top of that, hunt-for-duration on the part by life insurers manifests itself more during times of low interest rates. This is indicated by the positive and statistically significant coefficient on the interaction term $ED \times Low$. With regard to the magnitude of the results, during times of high interest rates, a one standard deviation of increase in a bond's excess duration (4.04) predicts a 1.94% (= 0.48×4.04) increase in life insurers' net purchases through the secondary market. This is equivalent to 13.85% of the standard deviation of the dependent variable. In addition, in times of low interest rates, a one standard deviation increase in the excess duration (4.04) is associated with a 2.34% (= (0.48+0.10)×4.04) increase in life insurers' holdings acquired from secondary market. This equals 16.70% of the standard deviation of the dependent variable.

After controlling for yield spread in Column [3] of Table X, the results with regard to bond excess duration in high and low-interest-rate periods remain similar to Column

Table X: Life insurers: Secondary market transactions

Dep. Var: Quarterly change in holdings by life insurers			
	[1]	[2]	[3]
Excess duration (ED)	0.48***	-	0.44***
	[0.03]	-	[0.02]
ED × Low	0.10***	-	0.06**
	[0.03]	-	[0.03]
Yield spread (YS)	-	2.59***	0.94***
	-	[0.26]	[0.24]
YS × Low	-	1.47***	0.21
	-	[0.29]	[0.27]
NAIC1	0.47	0.88	0.55
	[0.88]	[1.00]	[0.91]
NAIC1 × Low	-0.42	0.35	-0.08
	[1.06]	[1.16]	[1.09]
Turnover	1.16***	1.27***	1.19***
	[0.08]	[0.08]	[0.08]
Turnover × Low	0.75***	0.99***	0.80***
	[0.10]	[0.10]	[0.10]
Issuer-Quarter FE	Yes	Yes	Yes
N	155504	155504	155504
R^2	0.33	0.32	0.33

Notes: This table reports results from regression of life insurers' secondary market transactions of investment-grade corporate bonds. The dependent variable is the percentage change since the previous quarter in life insurance sector's total holdings of a bond transacted by life insurers in the current quarter. The independent variables are bond characteristics as well as their interaction terms with dummy variable *Low*, which equals one for the periods after 2009Q1 when the 1-year Treasury yield is below 1%. Excess duration of a bond is its duration minus market benchmark defined in equation (5). Yield spread is end-of-quarter yield to maturity over the closest benchmark Treasury bond. Turnover is log of total trading volume in the current quarter divided by amount outstanding. NAIC1 is an indicator variable equal to one for bonds in NAIC1 rating group. All bond characteristics (except NAIC1 dummy) are winsorized at the top and bottom 5%. Observations with dependent variable above 100% are dropped. Retiring bonds are excluded. Bonds with total holdings never above $10 million are dropped. All regressions include bond issuer-quarter fixed effects. Standard errors reported in brackets are clustered at the bond issuer level. The symbols ***, **, and * indicate significance levels at 1%, 5%, and 10%, respectively.

[1]. Comparing the coefficients on the variable YS and the interaction term $YS \times Low$ in Columns [2] with [3], we notice that with inclusion of excess duration, the effect of yield spread in times of high interest rates is significantly weakened; and the additional positive impact of yield spread in times of low interest rates disappears. This could serve as a piece of evidence that the propensity of life insurers to buy (sell) more bonds with higher (lower) yield is primarily driven by life insurers loading on longer duration.

To further investigate how life insurers make their secondary market investment decisions in accordance with fluctuations in interest rates, I adjust the specification in equation (10) by replacing the dummy variable Low_t with Δr_{t-1}, which is the quarterly change in 1-year Treasury yield lagged by one quarter. In particular, I estimate the following regression:

$$PctChg_{j,t} = \beta_0 + \beta_1 \cdot ED_{j,t} + \beta_2 \cdot YS_{j,t} + \beta_3 \cdot \Delta r_{t-1} + \beta_4 \cdot ED_{j,t} \times \Delta r_{t-1} + \beta_5 \cdot YS_{j,t} \times \Delta r_{t-1} + \gamma' X_{j,t} + \epsilon_{j,t}, \tag{11}$$

where the variables $PctChg_{j,t}$, $ED_{j,t}$, and $YS_{j,t}$ are defined in the same way as in the regression specification (10). The vector $X_{j,t}$ includes control variables turnover, NAIC1 dummy, and their interaction terms with the interest rate change Δr_{t-1}. Bond issuer-quarter fixed effects are included. The standard errors are clustered at the bond issuer level. Again, retiring bonds (with amount outstanding reduced by more than 50% due to calls, maturity, conversion, etc.) are excluded.

The specification in equation (11) allows us to test the effect of bond excess duration on life insurers' trades conditional on interest rate changes. Table XI presents two separate sets of results for the high and low interest rate regimes. The coefficient of interest, β_4, is on the interaction term $ED_{j,t} \times \Delta r_{t-1}$. If a reduction in the interest rate leads life insurers to hunt for duration, one would expect the coefficient β_4 to bear a negative sign. As shown in Column [6], the estimate for the interaction term $ED_{j,t} \times \Delta r_{t-1}$ is negative and statistically significant, indicating that in times of low interest rates, following a 1% decrease in 1-year

Table XI: Life insurers: Secondary market transactions, continued

Dep. Var: Quarterly change in holdings by life insurers	High rate			Low rate		
	[1]	[2]	[3]	[4]	[5]	[6]
Excess duration (ED)	0.48***	-	0.44***	0.58***	-	0.49***
	[0.03]	-	[0.03]	[0.02]	-	[0.02]
ED $\times \Delta r$	0.01	-	-0.02	-0.18***	-	-0.22***
	[0.04]	-	[0.04]	[0.07]	-	[0.07]
Yield spread (YS)	-	2.59***	0.94***	-	4.06***	1.22***
	-	[0.26]	[0.24]	-	[0.15]	[0.14]
YS $\times \Delta r$	-	1.52***	-0.19	-	1.20**	-1.28**
	-	[0.51]	[0.53]	-	[0.60]	[0.60]
NAIC1	0.53	0.91	0.61	0.09	1.26**	0.5
	[0.88]	[1.01]	[0.90]	[0.57]	[0.59]	[0.58]
NAIC1 $\times \Delta r$	-3.82**	-3.95**	-3.89**	-1.56	-0.19	-1.32
	[1.82]	[1.90]	[1.84]	[2.69]	[3.17]	[2.71]
Turnover	1.16***	1.28***	1.19***	1.92***	2.28***	2.01***
	[0.08]	[0.08]	[0.08]	[0.06]	[0.07]	[0.07]
Turnover $\times \Delta r$	0.29**	0.31**	0.28*	1.07***	1.52***	1.08***
	[0.14]	[0.15]	[0.15]	[0.23]	[0.24]	[0.23]
Issuer-Quarter FE	Yes	Yes	Yes	Yes	Yes	Yes
N	54811	54811	54811	100693	100693	100693
R^2	0.32	0.32	0.33	0.33	0.32	0.33

Notes: This table reports results from regression of life insurers' secondary market transactions of investment-grade corporate bonds in the high- (before 2009Q1) and low- (after 2009Q1) interest rate regime. The regime split is based on 1-year Treasury yield level of 1%. The dependent variable is the percentage change since the previous quarter in life insurance sector's total holdings of a bond transacted by life insurers in the current quarter. The independent variables are bond characteristics as well as their interaction terms with change in 1-year Treasury yield lagged by one quarter. Excess duration of a bond is its duration minus market benchmark defined in equation (5). Yield spread is end-of-quarter yield to maturity over the closest benchmark Treasury bond. Turnover is log of total trading volume in the current quarter divided by amount outstanding. NAIC1 is an indicator variable equal to one for bonds in NAIC1 rating group. All bond characteristics (except NAIC1 dummy) are winsorized at the top and bottom 5%. Observations with dependent variable above 100% are dropped. Retiring bonds are excluded. Bonds with total holdings never above $10 million are dropped. All regressions include bond issuer-quarter fixed effects. Standard errors reported in brackets are clustered at the bond issuer level. The symbols ***, **, and * indicate significance levels at 1%, 5%, and 10%, respectively.

Treasury yield, the positive association of bond excess duration on life insurers' secondary market transactions becomes almost 45% ($= 0.22/0.49 \times 100$) stronger. Notice that in times of high interest rates, the slope of excess duration on secondary market transaction doesn't vary with rate changes, as the coefficient on the interactions term $ED_{j,t} \times \Delta r_{t-1}$ in Column [3] is zero.

Overall, findings in this section about life insurers' trading activities in the secondary market are consistent with those found in the primary market: life insurers acquire bonds with higher duration. Such hunt-for-duration behaviour is more pronounced following negative interest rate changes over the period of low interest rates.

7 Implications of hunt-for-duration

In the previous sections, I have documented that life insurance companies hunt for duration through rebalancing their portfolios towards bonds with higher duration following drops in interest rates induced by monetary policy. In this section, I investigate whether hunt-for-duration by life insurers can have implications for bond prices. I hypothesize that a transition into a low interest rate environment spurs an increase in life insurers' demand for bonds with high duration, thereby creating an upward price pressure in the valuations of high duration bonds.

To test the hypothesis regarding the price pressure exerted by life insurers' hunt-for-duration behaviour, I examine the path of bond abnormal returns around life insurers' purchases. The procedure is as follows. First, for each quarter, bonds are grouped into quintiles based on their excess duration. Second, I define net trade by life insurers of a given bond-quarter as life insurers' total trading volume in percent of total amount outstanding. For each quarter, I rank bonds with positive net trade, and sort them into quintiles. The top quintile is composed of bonds that are most heavily bought by life insurers, whereas the bottom quintile contains bonds that life insurers buy most lightly. Next, I form four separate portfolios, including (1) bonds in the top two quintiles of excess duration and in the top quintile of net purchase, denoted as portfolio D5B5; (2) bonds in the top two quintiles of excess duration and in the bottom quintile of net purchase, denoted as portfolio D5B1; (3) bonds in the bottom two quintiles of excess duration and in the top quintile of net purchase, denoted as portfolio D1B5; and (4) bonds in the bottom two quintiles of excess duration and in the bottom quintile of net purchase, denoted as portfolio D1B1. Finally, I compute the quarterly equal-weighted average abnormal returns (AAR) of bonds in each of the four portfolios, using the characteristics-based procedure in Bessembinder et al. (2009). To adjust for risk, the quarterly abnormal return of a given bond is computed as its raw return (in equation (1)) minus the return on the benchmark portfolio to which it belongs.[21]

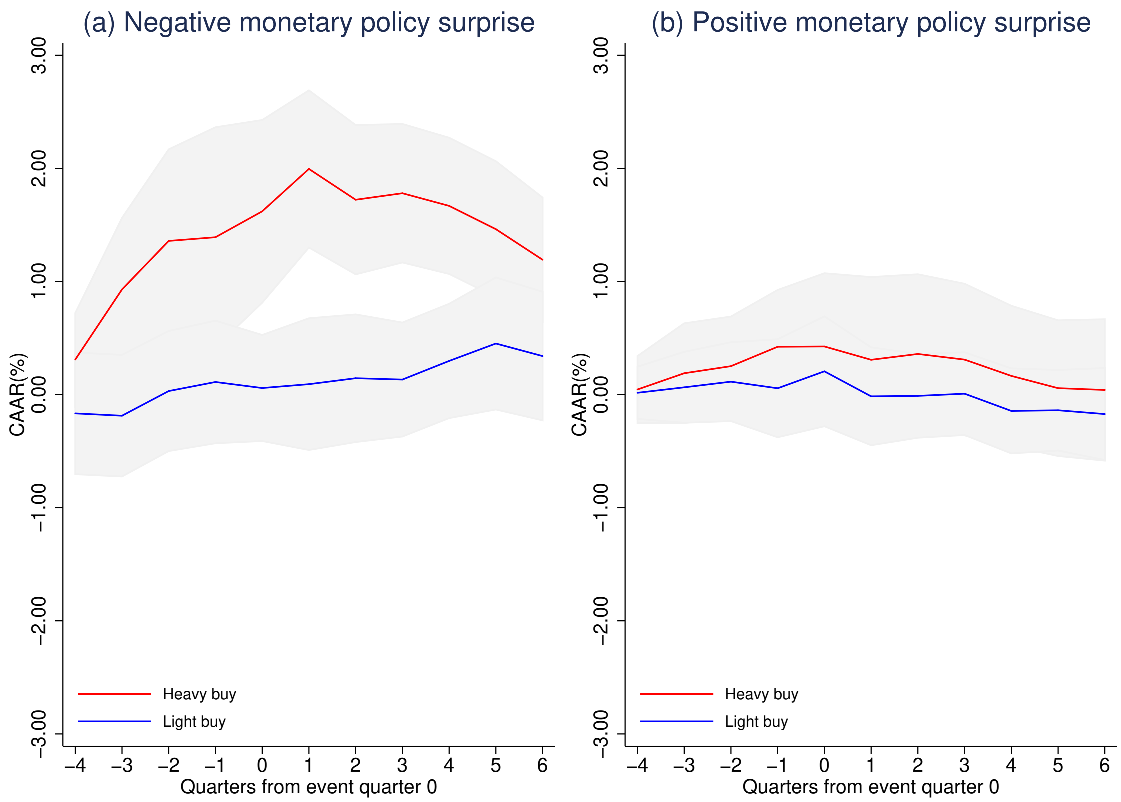
The sample period is split into quarters with negative and positive monetary policy shocks. The split is based on the quarterly monetary surprises obtained by averaging the futures surprises on FOMC days.[22] I consider bonds in the top two quintiles of excess duration most heavily bought by life insurers (i.e., bonds in portfolio D5B5) following a quarter with a negative monetary policy shock as bonds involved in hunt-for-duration-motivated trades. To see whether hunt-for-duration can bear price impacts, I compare the cumulative average abnormal returns (CAARs) of portfolio D5B5 and portfolio D5B1 (bonds in top two quintiles of excess duration that are lightly bought by life insurers). Figure IX plots the CAARs for the two portfolios by event quarters with negative and positive monetary shocks in panel (a) and (b) respectively. Table XII tests whether the CAARs between the two portfolios are different (see columns [1] to [2] and [5] to [6]).

Panel A of Figure IX shows that bonds in the top two excess duration quintiles purchased

[21]The portfolio benchmarks are created based on bond credit rating and remaining time-to-maturity. At the end of every quarter, bonds are first segmented into three time-to-maturity groups (1 to 5 years, 5 to 10 years, and more than 10 years) and then three rating groups (AAA&AA, A, and BBB). This gives a total of nine groups of bonds. For each group, the equal-weighted return is computed and used as the benchmark portfolio return.

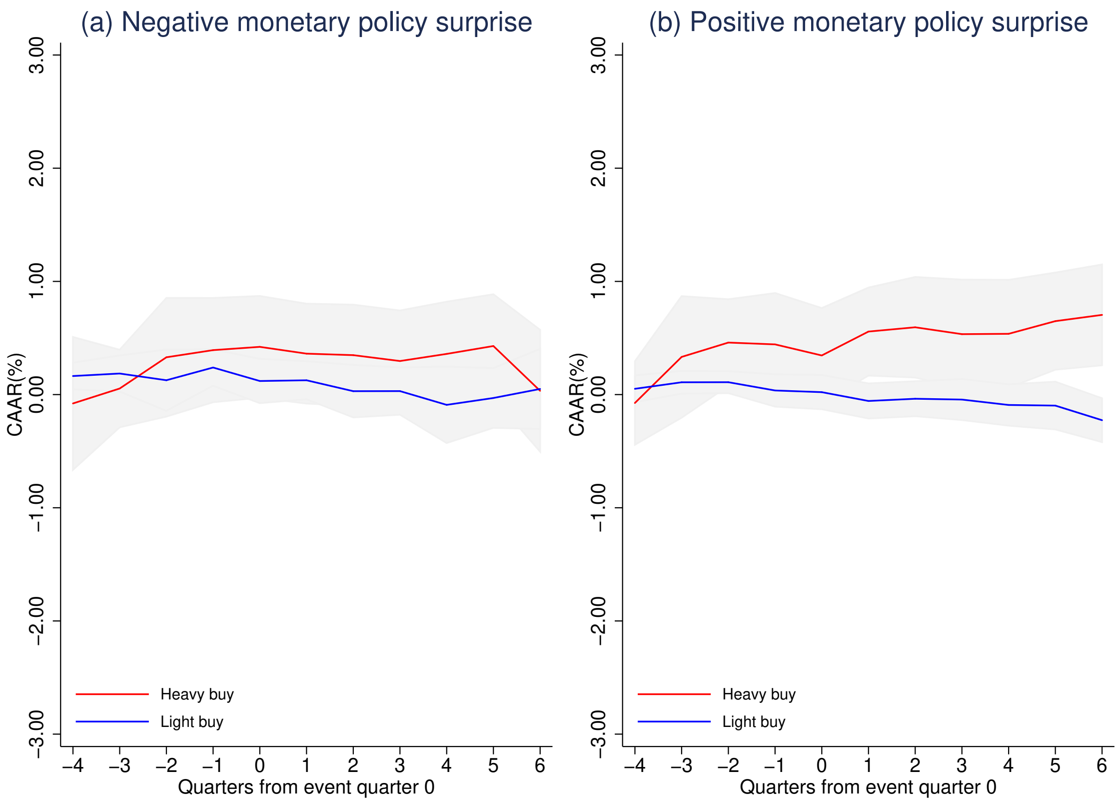
[22]Details on calculation of quarterly average surprises are discussed in Section 5.2.

Figure IX: Quarterly cumulative abnormal returns around life insurers' purchases: bonds in top two quintiles of excess duration



Notes: This figure plots the cumulative average abnormal returns (CAARs) for bonds in the top two quintiles of excess duration grouped by life insurers' net trade, four quarters before, during, and six quarters after the event quarter. The event quarters are split into those with a negative (panel A) and positive (panel B) monetary policy surprise. Net trade is defined as life insurers' total trading volume in percent of total amount outstanding. Bonds with positive net trade by life insurers are sorted into quintiles, with "heavy buy" ("light buy") denoting the top (bottom) quintile comprised of bonds most heavily (lightly) bought by life insurers following the the event quarter. CAARs are measured as quarterly returns in excess of the equal-weighted average return of bonds with similar credit rating and time to maturity as in Bessembinder et al. (2009). The grey area represents the 90% confidence interval.

Figure X: Quarterly cumulative abnormal returns around life insurers' purchases: bonds in bottom two quintiles of excess duration



Notes: This figure plots the cumulative average abnormal returns (CAARs) for bonds in the bottom two quintiles of excess duration grouped by life insurers' net trade, four quarters before, during, and six quarters after the event quarter. The event quarters are split into those with a negative (panel A) and positive (panel B) monetary policy surprise. Net trade is defined as life insurers' total trading volume in percent of total amount outstanding. Bonds with positive net trade by life insurers are sorted into quintiles, with "heavy buy" ("light buy") denoting the top (bottom) quintile comprised of bonds most heavily (lightly) bought by life insurers following the the event quarter. CAARs are measured as quarterly returns in excess of the equal-weighted average return of bonds with similar credit rating and time to maturity as in Bessembinder et al. (2009). The grey area represents the 90% confidence interval.

Table XII: Add caption

	Negative monetary shock				Positive monetary shock			
	Top 2 duration quintiles		Bottom 2 duration quintiles		Top 2 duration quintiles		Bottom 2 duration quintiles	
T	Heavy - Light CAAR (%)	t-stat	Heavy - Light CAAR (%)	t-stat	Heavy - Light CAAR (%)	t-stat	Heavy - Light CAAR (%)	t-stat
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
-4	0.48	1.62	-0.24	-0.60	0.03	0.18	-0.13	-0.56
-3	1.12	2.83	-0.13	-0.51	0.12	0.49	0.22	0.69
-2	1.33	3.25	0.20	0.48	0.14	0.63	0.35	1.48
-1	1.28	2.62	0.15	0.45	0.37	1.31	0.41	1.38
0	1.56	3.18	0.30	0.84	0.22	0.78	0.32	1.32
1	1.90	3.85	0.24	0.72	0.32	0.84	0.61	2.38
2	1.58	3.26	0.32	0.89	0.37	1.06	0.63	2.12
3	1.65	4.28	0.27	0.82	0.30	0.81	0.58	1.81
4	1.37	3.33	0.45	1.13	0.31	0.82	0.63	1.84
5	1.01	2.08	0.46	1.21	0.20	0.53	0.75	2.26
6	0.85	1.75	-0.02	-0.04	0.21	0.54	0.93	2.74

Notes: This table reports the difference in cumulative average abnormal returns (CAARs) for bonds in the top and bottom two quintiles of excess duration grouped by life insurers' net trade, four quarters before, during, and six quarters after the event quarter. The event quarters are split into those with a negative (columns [1]-[4]) and positive (columns [5]-[8]) monetary policy surprise. Net trade is defined as life insurers' total trading volume in percent of total amount outstanding. Bonds with positive net trade by life insurers are sorted into quintiles, with "heavy buy" ("light buy") denoting the top (bottom) quintile comprised of bonds most heavily (lightly) bought by life insurers following the the event quarter. CAARs are measured as quarterly returns in excess of the equal-weighted average return of bonds with similar credit rating and time to maturity as in Bessembinder et al. (2009).

heavily by life insurers during quarters following a negative monetary shock exhibit striking positive abnormal returns. Over the first quarter after the negative monetary policy surprise hits, the CAARs for the heavy buy group is 1.9% more positive than the light buy group with a t-statistic of 3.85 (as reported in columns [1] and [2] of Table XII). As in Coval and Stafford (2006) and Dessaint et al. (2019), to differentiate life insurers bringing information into prices from exerting price pressure, I look for evidence of price reversals through extending the time horizon from $t-4$ to $t+6$. The upside-down V shape price pattern in Panel A of Figure IX indicates that the upward pattern in abnormal returns eventually reverses. After six quarters that follow a negative monetary policy surprise, the difference in CAARs between the heavy buy group and the light buy group shrink to 0.85 with a t-statistic of 1.75. In panel B of Figure IX, I find no patterns of price pressure for the event quarters with a positive monetary policy surprise. The CAARs are relatively flat, and there is no significant difference between the heavy buy group and the light buy group (see columns [5] and [6] of Table XII).

Figure X repeats the calculations of Figure IX, but with the bonds in the bottom two quintiles of excess duration. There is no sign of a CAAR pattern consistent with price pressure for event quarters with either a negative or positive monetary policy surprise (see columns [3] to [4] and [7] to [8] of Table XII). To put all results above into a difference-in-difference perspective: For quarters with a positive monetary policy shock, there is no upward price pressure from life insurers' buying of bonds with either high or low excess duration. For quarters with a negative monetary policy, while there is upward price pressure from life insurers buying of bonds with high excess duration, the effect is absent for bonds with low excess duration. Hence, the results demonstrate that the price pressure is generated by life insurers' purchases associated with hunt-for-duration as the interest rate declines.

As an alternative approach to evaluate the price impact exerted by life insurers, I calculate the calendar-time portfolio returns to an investment strategy that involves bonds recognized as those purchased by life insurers' for the purpose of hunt-for-duration. Bonds involved in hunt-for-duration-motivated transactions are identified as those in the top two quintiles of excess duration bought by life insurers following a quarter with negative monetary policy shock. I use the overlapping portfolio formation method similar to Jostova et al. (2013). In particular, for each month t, I check if the quarter prior to the month t follows a negative monetary policy shock. If yes, I form a long-short strategy with a portfolio which is long in bonds purchased by life insurers and short in bonds with no purchase by any life insurers during the quarter. Portfolio returns are equally weighted across their constituent bonds. The overall month- t return of the strategy is the equally weighted average month t return of strategy implemented in the prior month and strategies formed up to twelve months earlier.

To adjust the portfolio returns for risk exposures, I estimate the intercepts (i.e., alphas) from the five-factor model developed in Fama and French (1993). In particular, the following equation is estimated:

$$r_{p,t} = \alpha + \beta^{'} F_t + \epsilon_{p,t}, \tag{12}$$

where $r_{p,t}$ is the month-t return of the long-short strategy described above. F_t includes equity (MKT, SMB, HML) and bond ($TERM, DEF$) factors, where MKT, SMB, and HML are returns on the market, size, and book-to-market factors of Fama and French (1993), $TERM$ is the difference in returns between five-year Treasury bond and 3-month Treasury bill. DEF is the difference in returns between investment-grade and high-yield corporate bonds (BofA Merrill Lynch index).

Table XIII reports the calendar-time portfolio regressions of the long-short investment strategy described above. The average monthly abnormal returns are represented by the intercepts (alphas) from the regression model in equation (12). The exercises are repeated for both the bottom and top excess duration groups. For the top excess duration quintile, the monthly abnormal returns are economically large and statistically significant: the alpha is -0.19% with significance level at 1%. However, the pattern disappears for the bottom

Table XIII: Calendar-time portfolio regressions

	Bottom quintile	Top quintile
	[1]	[2]
Alpha	-0.045**	-0.191***
	[0.018]	[0.038]
TERM	0.045*	0.285***
	[0.025]	[0.064]
DEF	0.026	-0.006
	[0.019]	[0.036]
MKT	-0.006	0.013
	[0.008]	[0.014]
HML	-0.005	-0.014
	[0.010]	[0.021]
SMB	0.006	-0.003
	[0.009]	[0.023]
N	141	141
R^2	0.06	0.38

This table presents the result of the calendar-time portfolio regression of an investment strategy following life insurers' hunt-for-duration-motivated purchases (Column [2]). The regression specification is

$$r_{p,t} = \alpha + \beta^{'} F_t + \epsilon_{p,t},$$

where $r_{p,t}$ is the month-t return of the long-short strategy which is long in bonds purchased by life insurers and short in bonds with no purchase by any life insurers in the top quintile of excess duration during the quarters following a negative shock. F_t includes equity (MKT, SMB, HML) and bond ($TERM, DEF$) factors, where MKT, SMB, and HML are returns on the market, size, and book-to-market factors of Fama and French (1993), $TERM$ is the difference in returns between five-year Treasury bond and 3-month Treasury bill. DEF is the difference in returns between investment-grade and high-yield corporate bonds (BofA Merrill Lynch index). Column [1] reports the similar long-short strategy with bonds in the bottom quintile of excess duration. Standard errors are in reported in brackets. The symbols ***, **, and * indicate significance levels at 1%, 5%, and 10%, respectively.

excess duration quintile: the alpha is -0.04%, which is small in economic terms. The results verify the findings in earlier part of this section: Life insurers' hunt-for-duration-motivated purchases can engender price impacts.

8 Conclusion

This paper demonstrates that life insurers, who are the largest players in the corporate bond market, shift their corporate bond portfolios towards bonds with longer duration as the interest rates decline to historical lows since the 2008 financial crisis. Evidence for hunt-for-duration is found not only from snapshots of life insurers' bond holdings, but also from their bond transaction activities. Moreover, a comparison with mutual funds confirms that hunt-for-duration is not a general feature in the corporate bond market when the interest rates are low, but a specific one accounted for by life insurers' interest rate risk hedging to ensure better duration matching between their assets and liabilities. Finally, I find corroborating evidence that hunt-for-duration on the part by life insurers can drive overpricing of corporate bonds when a negative monetary policy shock hits.

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